Factors Affecting Quality of Pavement Construction in Saudi Arabia

by

Mohamad Sayed Abdul-Hamid Al-Hassan

A Thesis Presented to the

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This thesis, written by **MOHAMAD SAYED ABDUL-HAMID AL-HASSAN** under the direction of his Thesis Advisor and approved by his Thesis Committee, has been presented to, and accepted by the Dean of the College of Graduate Studies, in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE** in **CONSTRUCTION ENGINEERING AND MANAGEMENT.**

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التخصص : هندسة وإدارة التشييد
التاريخ : ٤ يناير ١٩٩٣م

إن عملية تشييد طبقات الرصف الزفتية في المملكة العربية السعودية تواجه عدة صعوبات منها كثافة المرور والمناخ وجودة المواد المستخدمة التضاريس ، مما جعل عملية التشييد تتطلب خبرة ودراية كبيرة لتطوير تصاميم الأرصفة وطرق بنائها بشكل يمكنها من تقديم أداء جيد خلال فترة عمرها التصميمي . إن الهدف الأساسي لهذه الرسالة هو تحديد تلك العوامل المؤثرة علي جودة طبقات الرصف الزفتية لطرق المملكة السريعة خلال عملية التشييد . لقد تم إرسال استبيانات لمقاولي الطرق السريعة في جميع أنحاء المملكة لأخذ آرائهم في تلك العوامل ، وتم تبويب المعلومات على أساس مبدأ موشر الأهمية .

لقد أظهرت النتائج أن بعض العوامل التي لها آثار أساسية موجودة في المملكة مما تؤثر على جودة طبقات الرصف الزفتية للطرق السريعة ، ومن تلك العوامل :

١ - اختيار المقاول ذو العطاء الأقل، ٢ - عدم تصميم الطبقات والخلطة الزفتية حسب الظروف الاقليمية للمنطقة (كثافة المرور، الحرارة ، نوعية التربة) ، ٣ - جودة المواد المستخدمة في الخلطة الزفتية (الحصى ، الزفت ، ٤ - تدرج الحصى المستخدم في الخلطة الزفتية، ٥ - الطريقة المستخدمة في تقييم العمل المنفذ .

إن تلك العوامل توضح الحاجة لتطبيق نظام فعال لمراقبة وضمان الجودة لمشاريع الطرق في المملكة لتحسين جودتها .

لقد اتضح من تحليل المعلومات أن معامل الاتفاق بين أراء المقاولين كان عالياً .

وفي نهاية البحث قدمت بعض التوصيات بشأن تحسين جودة طبقات الرصف الزفتية ، كما قدمت بعض الاقتراحات بشأن المواضيع التي يمكن التعمق في دراستها مستقبلاً .

درجة الماجستير في العلوم
جامعة الملك فهد للبترول والمعادن
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THESIS ABSTRACT

Student name: Mohamad Sayed Abdul-Hamid AL-Hassan

Thesis Titel : Factors Affecting Quality Of Pavement Construction In Saudi Arabia

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Asphalt pavement's quality is affected by many varible interrelated factors (i.e traffic, climate, material's quality,...ect). Such factors make pavement construction process complex. In the past few years, some of the newly constructed asphalt pavement in the Kingdom's Highways have shown some type of distress requiring re-habilitations at an early age. The main objective of this study is to identify factors affecting asphalt pavements' quality on the Kingdom's Highways during its construction. The effect of the factors were measured by their Effect Index throughout a questionnaire survey of the Kingdom's Highway Contractors.

The results show that some factors which have major effect and effect levels occurred in the Kingdom. such as selection of the lowest bidder; qualification of owner inspection team; acceptance procedure; and aggregate and asphalt cement quality. This result indicates the need to implement aprecise QA/QC program to improve asphalt pavements' quality on the Kingdom's Highways.

MASTER OF SCIENCE DEGREE

KINF FAHD UNIVERSITY OF PETROLEUM AND MINERALS

Dhahra, SAUDI Arabia

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Chapter I

Introduction

1.1- General

In highway construction projects, the ultimate aim of an owner is to build a pavement that will have good serviceability under the local conditions of climate and traffic that the pavement will be exposed to during its anticipated life and result in minimum overall costs. Good serviceability of asphalt pavement is the result of (a) good planning including site location, soil survey, and an analysis of available materials for construction; (b)adequate structural design, and specification of the pavement; (c) proper selection of construction materials and good construction practices at the plant and site operations; and (d) good quality control and inspection in each of these areas (Webb 1986).

The minimum overall costs of the projects include not only the immediately recognizable costs, such as the contract amount and the engineering cost, but also the long term costs, maintenance of the completed facility and costs of rehabilitating the projects. These long term costs, which are considered not part of the cost of a project, are at present, one of the biggest drains on highway construction (LaHue 1990). The two objectives (good pavement performance, and minimum overall costs) are considered to be the main goals that any highway agency seek to achieve in any highway construction project.

A highway asphalt concrete pavement's performance is affected by many interacting factors such as the pavement's structural design and environmental conditions (temperature and moisture). Pavement deteriorates with the passage of time; the rate of deterioration varies widely depending upon the above mentioned factors and the amount of maintenance performed by the highway agency during the service life of the pavement. However, good quality pavements will reduce the rate of deterioration as much as possible.

1.2- Highway Construction Practice in Saudi Arabia

Saudi Arabia covers more than two million km2, and this large area needs a good highway network to connect its parts, and shorten the distance between large cities.

The area of Saudi Arabia encompasses extremely variable environmental conditions. There are three totally different areas where a highway may be constructed. Each area represents a unique set of design and construction challenges to both designers and contractors. These areas are (a) desert or sand dune areas; (b) mountainous areas; and (c) sabkha or salt flat areas. Each area has its own difficulties and requirements in terms of highway pavement design, specification, construction and performance. At the same time, the quality of materials (e.g. aggregate quality) which are used in constructing the pavement varies according to their availability in each area. This may lead to different pavement performance and service life for a highway that may cross more than one area. (Highway Design and Construction 1988).

1.3- Statement of the problem

During the past few years, the newly constructed asphalt concrete layers on several of the Kingdom's highways have experienced some type of pavement distress. There are various parameters which contribute to this pavement distress; one of these is the level of quality control / quality assurance during the construction period.

It is the purpose of this research to identify the factors affecting the quality of the constructed highway asphalt concrete pavement in Saudi Arabia.

1.4- Significance of the study

Asphalt concrete pavement's quality and durability have always been a major concern to pavement engineers and contractors. The production of poor quality or non-conformance pavement layers will result in poor performance, less service life, and high maintenance costs or reconstruction of the pavement at an early age. There is a need to conduct a study to identify the factors affecting the quality of the constructed pavement during the project construction process (design and construction phases) which may be responsible for unsatisfactory pavement quality level and poor performance.

1.5- Objectives of the Research

The aim of this research is to identify factors affecting the quality of the constructed highway asphalt concrete pavement in Saudi Arabia.

1.6- Scope and Limitation

The scope of the research is limited to contractors who are dealing with highway asphalt concrete pavement projects in Saudi Arabia. The research will identify the factors affecting the quality of the constructed asphalt concrete pavement in the Kingdom's highway construction projects. The study includes only the asphaltic course of the pavement.

1.7- Organization of the Thesis

The thesis is divided into five chapters. Chapter I includes an introduction of the problem, the significance of the study, the objective of the study, and the scope and limitation of the study. Chapter II discusses the various factors affecting the quality of asphalt concrete pavements during the construction process. Chapter III discusses the research methodology. Chapter IV presents the result of the study. The last chapter namely, chapter V, includes an overall summary of the research, conclusions and recommendations for future studies.

Chapter II

Factors Affecting Asphalt Concrete Pavement Quality

Asphalt concrete pavement performance is a function of the pavement quality which includes pavement structural design, materials used to construct it and the process by which these materials are built into the pavement . There are many factors throughout the project's design and construction phases, which may affect the quality of the constructed pavement. The project owner highway agency and contractor should be aware of these factors and their relation to the final pavement quality so that the pavement is designed and constructed with the objective of achieving the desired quality.

Throughout this chapter, factors affecting asphalt concrete pavement quality will be discussed. These factors are classified into four categories. These categories are: a) Managerial; b)Design and Specification; c)Construction Process; and d) Acceptance Procedure.

2.1- Managerial Factors

In any construction project, contract management will have a direct effect on the final quality that is achieved. The most important element in successful contract management is people, their attitude, skill and knowledge. The following points discuss the effect of managerial related factors on the final product quality.

a. Clarity of responsibilities and authorities

During the construction phase, the desired quality is achieved through a team effort of the owner, consultant, contractor and any of their staff who may be involved. To achieve the desired quality each member of the team must assume a share of the responsibility and should work competently in a timely fashion, fulfilling his obligations in cooperation with the other members of the team (Fellow and Regmi 1990). Sandberg (1987) expressed the project quality in equation form as "owner quality x engineer quality x contractor quality = project quality". Failure of any one of the team members to perform properly will negatively affect the effort of the whole team. In order to perform properly each member should understand his authority, responsibility, duty and limitations during the construction phase.

When the members responsibilities and authority are clearly defined and properly allocated a friendly relationship will exist among the members. Within this friendly climate, more effort is focused in achieving the desired quality by all members in a cooperative manner.

b. Owner inspection team

During the construction phase, the contractor has the responsibility of delivering an asphalt concrete pavement that complies with the contract requirements. To ensure that the contractor's operation is carried out in accordance with the contract requirements and that the constructed pavement meets the specification, on-site inspection by the owner or the owner's representative is required (Tenah 1986). The major function of the on-site inspection is to ensure that the plan and specification are followed, to verify that the finished pavement meets the project's requirements and to help the contractor avoid making errors. In order to accomplish this function, the inspection team of the owner (either in-house or contracted) must have the qualifications and capabilities to perform its duties and responsibilities effectively.

The owner's inspection team should also understand the design of each element of the pavement being specified and its practical functions. If the team fails to recognize what attributes of an element are important, the pavement may be constructed differently than the owner expected, or the finshed pavement might not satisfy minimum requirements resulting in a pavement with low quality (Gendell and Masuda 1988, and Jackson 1990).

c. Consultant Quality Control

In public construction projects, many governmental organizations establish their own internal quality control programs to monitor their on-going construction projects. However, sometimes, because of the complexity of the project, the special skills needed, or projects that have specialized and highly technical quality control requirements as in asphalt concrete pavement projects, the public agency usually hires specialized consultants to perform field quality control services (Clough 1981).

The project owner's decisions regarding the responsibility for quality control are direct and major factors in ensuring the quality of the finished project. He influences quality control by his criteria used in consultant selection, his ability in defining the desired quality level of the constructed product, the level of quality control supervision he desired and by his willingness to pay for these elements (Bayless 1986, and Erickson 1989). In selecting the consultant for performing quality control activities, the owner's best interest lies in the selection of a consulting firm on the basis of its skill and competence rather than its fees. The owner should consider the firm's technical experience, the qualification and experience of its staff, past performance in similar projects, present work load and capability to support the new project to be done, and the proposed approach in carrying out the quality control program (Bayless 1986, and Kasma 1987). In the U.S many highway agencies are requiring the contractors to take a more active role in the control of project quality by making them develop their own quality control programs. The agnecy or its consultant monitors and verifies the product quality and makes sure that the implemented quality control program is adequate for the required quality level (Burati 1986, Giendel and Masuda 1988, and Powell 1986).

d. Contractor's Prequalification

The degree of quality in the construction of a project is dependent on the capability of the contractor. It is very important to obtain a qualified and competent contractor to construct the project. To achieve this objective, construction contractors should be prequalified to ensure that their experience and capabilities (i.e equipment and labor) match the requirements of the project under consideration (Russel 1990).

Prequalification can aid the public agency in achieving successful and effective use of its monies by ensuring that it is a qualified, responsible and capable contractor who will construct the project. If the agency awards the construction contract without seeking proper verification of the contractor's capabilities or when the prequalification process is not effectively implemented, it may result in having a contractor who is not well suited to carrying out the project to its specified quality. This can result in a construction project with additional cost and/or poor quality (Fellow and Regmi 1990, and Russell 1990).

e. Selection of the Lowest Bidder

During a competitive process all classified pavement contractors can bid in a project in which the lowest bidder who offers the lowest total project cost is awarded the contract (Clough 1981, and Russell 1990). This is mandated for public work to achieve fairness between contractors, and to encourage efficiency and innovation by contractors so that the public agency can have a project at specified quality at the lowest possible cost.

Bids for construction services for a public project should be sought at the lowest price; however, awarding the contract solely based upon bid amount may result in selecting a contractor who is not qualified enough to construct the project to its specified quality, and while the bid price may be low, the final cost including cost of delays, default and unsatisfactory performance (rework to correct defective product) is likely to be substantial higher (Russell 1990). Bidding for the lowest price without seeking proper prequalification of the contractor results in poor quality most of the time, and the concept of construction projects at the lowest price may sometime place the quality of the project in a secondary role (Abdunnur 1981, and Sundberg 1987).

f. Contractor's Characteristics and Capabilities

Pavement construction involves the constructing of different layers such as subgrade, subbase, base, and asphalt concrete layers. Each layer utilizes different materials, equipment, and technical experience. For asphalt concrete layers, the construction phase involves selecting of the specified materials (aggregate and asphalt), mixing these materials according to a job mix formula at the mixing plant, and transporting the mixture to the project site where it is placed and compacted using special pavers and compaction roller equipment. A proper construction process during these operations often determines the overall quality and performance of the constructed pavement. Such a construction process can require different experience, financial resources, and equipment, to be used in constructing the pavement. Failure of the contractor in providing the adequate level of these resources will affect his capability in achieving the desired quality within time and budget. For an asphalt pavement construction project to achieve the desired quality,a contractor should have:

a)the necessary experience and technical qualification in asphalt pavement construction. A contractor's experience is always the basis for developing better and more economical ways to accomplish the work to its specified quality (Powell 1986).

b)adequate financial resources (working capital and bonding capacity) in order to give the owner financial protection in the event of a contractor's failure to perform according to the contract requirements, and to pay his financial obligations (Russell 1990). Inadequate contractor financial status can get the contractor off to a very poor construction start-up and may jeopardize the project quality.

c)the required management and technical personnel resources.

d)the necessary equipment to perform the work. In pavement construction projects equipment is considered to be as the key element. Their quantity, type, size, conditions, suitability and availability all play an important role in a contractor's performance and in achieving the specified pavement quality (Russel and Skibriewski 1988).

g. Amount of Work Subcontracted

Depending on the amount of work to be accomplished, the complexity involved, and the availability of construction equipment and skilled labor, the general contractors may subcontract portions of their work to subcontractors to accomplish the project. A qualified subcontractor is a specialist who is usually able to construct his work more quickly and lesser cost than the general contractor (Clough 1981).

In pavement works, the contract frequently limits the proportion of the total construction work that the contractor is allowed to subcontract. Extensive subcontracting can seriously complicate the overall scheduling of the project operations, lead to a serious division of project authority, fragmentize responsibility, and make the coordination of construction activities difficult. These problems can affect the contractor's capability in executing the project to its desired quality within time and budget requirements (Clough 1981, and Fellow and Regmi 1990).

h. Cost Escalation of Resources (Materials and Equipment)

During the bidding process, the contractor must estimate the total cost of the project. During the construction phase, if the actual cost of construction exceeds the bid amount, the resulting loss is borne by the contractor (Clough 1981). For construction areas where the cost of material and equipment operations represent a high proportion of the total cost, as in pavement construction, a change in these costs (price rising) may introduce difficulties for the contractor's financial capabilities in constructing the required work to its specified quality.

i. Financial Incentive for Higher Quality Production

A financial incentive (bonus) can be effective for project completion at an early time, but for quality of product it is questionable (Powell 1986). "Owners believed they needed no more quality than that specified in the bidding contract" (Echeverry et al 1988). However, the recognition of the life cycle cost concept which recognizes the impact of product quality on the product's useful life and maintenance cost have motivated many highway agencies to consider bonuses to contractors who produce a higher quality level than that specified. (Echeverry, et al, 1988). In order to provide a bonus, the agency must be convinced that it receives a tangible benefit, from the higher quality produced, in terms of extra service life (Kopac 1984, and Weed 1984).

To provide the bonus, many highway agencies have included a Value Engineering (VE) incentive in their construction contract to take advantage of the contractor's ingenuity and experience in getting the job done better than specified (higher quality) and at low cost.

j. Delay in Contractor Progress Payment

Progress payment is a periodic payment made to the contractor during a construction phase for the work being performed in that period. Since contractor usually depends on borrowed money to fund his operation, progress payment is very important for keeping his working capital at an adequate level, and for managing his cash flow for the payment of material, and subcontractors and for other financial obligations when they are due. Delay in payment or slow payment procedure by the owner to the contractor will impose serious problem in managing contractor cash flow operations, which may result in substantial borrowing of money at a hefty interest rate causing higher construction cost to the contractor. When the contractor feels that his payment is being delayed or unreasonably withheld for the work that he has performed in accordance with the contract, an adverse relationship may develop which may jeopardize the end product quality (Halstead and Hughes 1981).

2.2. Design and Spscification Factors

Quality problems (factors) are not limited to just the construction phase. Factors stemming from incomplete or inaccurate design or specification are frequently more serious, and more costly to correct than the factors caused during the construction phase, and may not be discovered until the project is completed or in use. During construction, these factors can result in confusion, poor quality construction, poor quality materials and problems in contract administration. The following points discuss the design and specification factors affecting pavement quality.

a. Pavement Design

The pavement design process involves the selection of paving materials and thicknesses of the pavement's layers for the anticipated traffic loading and climate conditions, and soil type to provide a satisfactory level of pavement performance during its service life. It has a significant influence on pavement performance regardless of how carefully construction materials and process are controlled during the construction phase. For instance a pavement constructed with high quality materials may provide unsatisfactory performance if its design is deficien (Knutson 1986).

Asphalt concrete pavement must have an adequate cross-section and must be structurally adequated to mitigate various forms of distress induced in the pavement from traffic and climate conditions, and soil type related factors existing along the roadway (Monismith et al. 1985, and Webb 1986). A pavement that is not designed according to these criteria may result in an inadequate pavement structure which will not provide the required load carrying capacity to handle the traffic, ending up in either collapse of the structure and the necessity of reconstructing the pavement at an early age or premature failure with increased maintenance cost (Weingarten et al. 1975).

b. Design Errors

The quality of the constructed pavement is not wholly dependent on the construction process and its control. While these are essential, quality begins with proper and accurate design information and procedure, and specification preparation (Erickson 1988). Design errors arising from the inadequate assumptions of engineers, and from inaccurate data related to traffic, climate, soil type and material characteristics are frequently more serious and costly to correct, than quality problems caused by a contractor's operation during the construction phase. Poor quality pavement that comes from engineering short-comings can be very subtle and may not be discovered until the pavement is constructed and in use. Corrections at this late stage are costly and time consuming (Burgess 1988, and Kasma 1987).

c. Project Owner Involvement during Design Phase

The owner has a basic responsibility during the design phase which involves (a) acquiring design services; (b) providing the needed information related to traffic volume, soil type and desired pavement properties; (c) monitoring and controling the design process; and(d) approving the final design. Because of the severity of quality problems that arise from engineering shortcomings, the owner should carry out his responsibility during design phase effectively to prevent any errors, omissions, inaccurate assumptions or data, or defects in the design.

d. Soil Type (Subgrade)

Soil (subgrade) is the foundation upon which the pavement structure is constructed. It is the layer which ultimately carries all traffic loads that are applied on the pavement. Thus, the pavement load carrying capacity and performance during its life will be dependent upon the strength and suitability of subgrade soil. To achieve an adequate pavement structural design and a quality riding surface, special consideration must be given to factors affecting subgrade soil such as material strength, moisture content, drainage characteristics,...etc. In order to achieve these design requirements, a comprehensive soil investigation must be completed prior to the design phase. The investigation should involve the type of soil that exists along the roadway, material strength, moisture content, durability, compactability and drainage characteristics (Knuston 1986).

e. Traffic Conditions

Pavements are designed according to traffic volume and type that the pavement will be exposed to. Traffic information that is used in the pavement design involves traffic volume, axle load, axle number, composition percentage of heavy trucks, tire pressure and expected traffic growth. The design of pavement requires reliable traffic information and accurate assumptions to develop proper pavement cross-sections with adequate load carrying capacity to handle the expected traffic during its life. If pavement design is not based on accurate traffic data, densifications can take place on the asphalt concrete layers resulting in pavement performance problems in terms of bleeding and rutting (Thay-Ming and Jenn-Fang 1988).

f. Environmental Conditions

Environmental factors, particularly those related to climate, can have a significant effect on the performance of a pavement (Meyer and Hudson 1988). The interaction of heavy traffic loads and temperature have a significant effect on the pavement performance in terms of reduction of its air void content, and modification of aggregate gradation and asphalt properties (Knight, et al. 1979). A fundamental knowledge of the climate and traffic loading effects on pavement performance and material behaviors when translated into pavement design requirements could permit optimum pavement design for the environmental and traffic conditions with limited deterioration throughout its service life.

g. Asphalt Concrete Pavement Cross-Section

Asphalt pavement cross-sections vary according to soil and pavement structure requirement. The cross-section's layers (i.e subgrade, sub-base, base, and asphalt layers) are composed of varying grades of materials, with that on top being the best grade.

Traffic to be served, strength and properties of the prepared subgrade, and strength and other influencing characteristics of the materials selected for the pavement layers must be considered in developing the pavement cross-section material and thickness design (Principle of Construction of Hot-Mix Asphalt Pavement 1983).

h. Specification Interpretation

Specifications constitute an important controlling contract document concerning the performance of construction work. They describe how a construction contract is to be administered,; the properties and quality of materials to be incorporated into a project, and the quality of workmanship (Clough 1981, and Gendell and Masuda 1988). For asphalt concrete pavements, mixture design requirements (i.e. design method, asphalt and aggregatet,...etc), and mixture properties (i.e. stability, durability,...etc) are often an essential part of the construction specifications. The adequacy of the specifications concerning these items is an important factor in material and construction process control and in determining the overall pavement quality and its performance during its service life (Ericson 1990).

Poor specifications or ambiguous and inconsistent statements will result in inconsistent and nonuniform interpretations of the specification requirements by the inspection team and contractor during the construction phase, and often reduce the quality of work. The inspector may have an interpretation of the specification that disagrees with that of the contractor. The result will be conflicts, disagreement, and claims between project's parties and projects that are constructed which might not satisfy minimum requirements or involve additional cost for either one or both parties. (Gendell and Masuda 1988, and Jackson 1990).

Specification interpretations that are fair and consistent will result in uniform specification enforcement which enhance the administration of the contract, create a friendly relationship between a projects parties and focus more effort on achieving a quality product by both parties.

The economic rewards or penalties of the contract and the quality of construction depend to a great extent on the clarity and completeness of the specification. The specification must be fair, reasonable and brief, yet sufficiently detailed to achieve the desired end quality and strike a balance between quality and cost. Each specification has a precise intent whether to exemplify the design of a given element, verify the performance by the contractor, or test a characteristic of the pavement (Jackson 1990). Specifications that tend to overspecify materials, equipment and the construction process with the aim of obtaining quality in the finished product have generally resulted in increased cost without adding anything to quality. Overspecifying of materials and equipment to be used and the construction process to be followed does not guarantee quality in the finished product. However, they may place the specifying agency in a position where they may be legally responsible for the quality of the constructed product, since all materials, equipment and construction methods are detailed in the specifications. (Burite 1986, Powell 1986, and Gendell and Masuda 1988).

Overspecifying of materials and the construction process can also introduce limitation on the options available to contractor for selecting sources of materials, equipment types and construction techniques. Such limitations discourage the use of new materials and equipment as well as innovative construction techniques that might improve the product quality and/or reduce the construction cost (Halstead and Huges 1981, and Gendell and Masuda 1988).

i. Mix Design

Designing a hot mix asphalt paving mixture is largely a matter of selecting and proportioning asphalt and aggregate materials with the objective of achieving the desired qualities and properties in the finished constructed asphalt pavements. The relative proportions of these materials will determine the physical properties of the mix and, ultimately, how the mix will perform as a finished pavement during its designed life (Principle of Construction Hot Mix Asphalt Pavement 1983).

The design process requires knowledge of the way the materials will behave under the loading and environmental conditions existing along the roadway. The mixture should be designed to provide certain desirable properties to mitigate specific modes of distress such as fatigue and rutting which are induced in the pavement from traffic and environmental related factors (Monismith et al. 1985). The design method should also take into account the effect of increase in traffic volume and load, the effect of the environment and the influence which the entire pavement structure has on the asphalt mix design.

j. Asphalt Concrete Mixtures Type and Characteristics

Hot mix asphalt paving mixture may be produced from a wide range of aggregate combinations. The mixtures are usually described on the basis of their aggregate gradation (dense graded mixture, open graded mixture,...etc) in which each has its own particular characteristics and properties suited for specific design requirements (Erickson 1989).

There are four characteristics which tend to influence the behavior of the mixture and its probable performance in a pavement structure. These characteristics are mix density, air voids, voids in the mineral aggregate, and asphalt content.

1) Mix Density:

The density of the compacted mix is particularly important, since high density of the finished pavement is essential for lasting pavement performance. The density of the mixture determined in the laboratory will become a standard which will be used to determine whether or not the contractor reaches the proper compaction level of the mixture during the construction phase. Because it is difficult to achieve the laboratory densities, specifications usually require pavement density to be a percentage of laboratory density (Principle of Construction of Hot Mix Asphalt Pavement 1983).

2) Air Voids:

Air voids are small air spaces or pockets of air that occur between the coated aggregate particles in the final compacted mix. A certain percentage of air voids is necessary in asphalt mixes to allow for some additional pavement compaction under traffic and to provide spaces into which small amounts of asphalt can flow during subsequent compaction. Insufficient air void content can lead to flushing, in which excess asphalt squeezes out of the mix to the surface. Too excessive air void content, on the other hand, will provide passageways through the mix for the entrance of damaging air and water (Webb 1986).

3) Voids in the Mineral Aggregate (VMA):

VMA are the air void spaces that exist between the aggregate particles and the compacted paving mixture including the spaces filled with asphalt (Webb 1986). The more VMA in the dry aggregate the more space is available for the film of asphalt. Since the thicker the asphalt film on the aggregate particles, the more durable the mix, specific minimum requirements for VMA are recommended and specified as a function of the aggregate size. If the VMA is decreased due to change in the gradations, variation in the mixture's characteristics (i.e. air void contnt and asphalt content) can result, affecting the desired mixture's properties.

4) Asphalt Content:

Asphalt content and its proportion in the mixture is critical and must be accurately determined in the laboratory and then precisely controlled during the mixing operation. Aggregate characteristics such as gradation and absorptiveness are directly related to optimum asphalt content. The finer the mix gradation, the larger the total surface area of the aggregate and the greater amount of asphalt required to uniformly coat the particles. Thus coarser aggregate require less asphalt than the finer aggregate due to lesser total aggregate surface area. The absorptiveness of the aggregate used in the asphalt paving mixture is critical in determining the optimum asphalt content, since enough asphalt must be added to the mix to allow for absorption and still coat the aggregate particles with an adequate film thickness (Webb 1986).

k. Asphalt Concrete Mixture's Properties

A mixture's properties, such as stability, durability, impermeability, workability, flexibility, fatigue resistance, and skid resistance, are essential in producing good hot mix asphalt pavement, which will function well in terms of performance during its design life. Ensuring that a hot mix asphalt mixture has each of these properties is a major goal of the mix design procedure. Failure of the design to provide the desired level of each of these mixture's properties may affect the performance level required of the pavement which may result in performance problems when the pavement is constructed and in use. The mixture's properties which must be considered for specific design situations are :

1) Stability:

The stability of an asphalt pavement is its ability to resist deformation, such as rutting and shoving, from imposed loads (traffic). A stable pavement maintains its shape and smoothness under repeated loading and high tire pressure where as an unstable pavement will develop ruts (channels), ripples (wash boarding), and other signs of shifting of the mixture. In addition, asphalt pavement must be able to resist the development of excessive rutting under standing loads and be resistant to shoving from decelerating and accelerating traffic. (Menismith, et al. 1985)

The stability of asphalt paving mixtures depends on internal fraction among aggregate particles and cohesion of the asphalt cement used in the mixture. Interparticle fraction is related to aggregate characteristics such as particle shape and surface texture. The more angular the shape of particles and the more rough their surface texture, the higher the stability of the mix will be. Cohesion is the binding force which results from the bonding ability of the asphalt. It varies directly with the rate of loading, the loaded area, and the viscosity of the asphalt. Excessive asphalt in the mix tends to lubricate the aggregate particles and lower the internal friction of the particle's formwork. A proper degree of both internal friction and cohesion in a mix prevents the aggregate particles from being moved past each other by the imposed traffic load. (Principle of Constuction Hot-Mix Asphalt Pavement 1983)

2) Durability:

An asphalt pavement's durability is its ability to resist disintegration which may be caused by environment (weathering) and traffic. Included are effects of changes in the asphalt characteristics as a result of oxidation, changes in aggregate characteristics resulting from degradation (breaking apart) or freeze-thaw effects and stripping of the asphalt films from the aggregate due to water and water vapor action (Monismith et al. 1985). The durability of an asphalt mixture can be promoted by using maximum asphalt content, a dense aggregate, and a well compacted mixture.

3) Impermeability:

Impermeability is the resistance of an asphalt pavement to the passage of air and water into or through it. This mixture characteristic is related to the air void content in the compacted mixture. The lower the air voide content the more permeable the mixture becomes. (Asphalt Technology and Construction Practices 1983)

4) Workability:

This mixture characteristics describes the ease with which paving the mixture can be placed and compacted. Mixtures with good workability are easy to place and compact, whereas those with poor workability are difficult to place and compact. Harsh mixtures (those mixtures having a high percentage of coarse aggregate) tend to segregate during handling and may be difficult to compact. Too high filler (material passing No. 200 sieve) content causes the mix to become gummy, making it difficult to compact. (Principle of Construction of Hot-Mix Asphalt Pavement 1983)

5) Flexibility:

Flexibility is the ability of an asphalt mixture to conform to the gradual settlement and movement of the base and subgrade without cracking. Asphalt pavement flexibility is a desirable characteristic since most subgrade layers are either settle (under loading) or rise (from soil expansion). The flexibility of an asphalt mixture is enhanced by high asphalt content and relatively open graded aggregates. (Asphalt Technology and Construction Practices 1983)

6) Fatigue Resistance:

Fatigue resistance is the ability of an asphalt pavement to bend repeatedly under wheel loads (traffic) without fracture. For mixtures with dense graded aggregate, the two primary factors affecting fatigue response are asphalt content and degree of compaction as measured by air void content. (Monismith et al. 1985)

7) Skid Resistance:

Skid resistance is the ability of an asphalt surface, particularly when wet, to minimize skidding or slipping of vehicle tires. Proper asphalt content and aggregates with a rough surface texture are the greatest contributors to obtaining high skid resistance. Unstable mixtures that tend to rut or bleed present serious skid resistance problems.

Mixture properties should be optimized for a given paving project. Each mixture characteristic, (i.e asphalt content, density,...etc), will have direct effect on each individual property. For example, high asphalt content is desirable for good durability, flexibility, fatigue resistance and low permeability, while low asphalt content is desirable for stability and skid resistance. A balance design must be obtained for a particular application to provide certain desirable mixture properties.

I. Job Mix Formula and Tolerances

The job mix formula is the receipt used by the plant to produce the final paving mixture; it includes information on aggregate material gradation, the selected asphalt cement, the temperature at which the mixture is to be produced, and mixing time. Since variations in the mix are inevitable during production, the job mix formula has built-in tolerances or limits that allow for reasonable variation in gradation and asphalt content, air void content and mixture density.

The job mix tolerances can have direct effects on the quality of the mixture produced and used in pavement construction. This can occur when the tolerances are either so tight that the contractor can not meet them or so loose that almost anything could pass (Gendell and Masuda 1988). A wide job mix tolerance can permit the use of marginal materials in mixture production in which the asphalt pavement could be penalized with shortened service life and performance problems under traffic and environmental conditions (Hay and Kopac 1986, and Hugess 1986).

2.3-Construction Process Factors

During the construction phase, the use of proper construction techniques is often considered to be the most important factor that determines the overall success of a project. The production of asphalt concrete pavement involves critical mixture preparation and construction steps during which that something can be neglected that will affect the performance of the pavement. The following points discuss factors that may affect the quality of the asphalt pavement during construction phase.

a. Contractor Quality Control

During the construction phase, the presence of poor quality pavement can result from a number of factors, such as a careless material handling process, unnoticed equipment defect, or an improper placement operation (e.g. the mixture's transportation, the uniformity of its placement and the compaction process). These contractor's operations can affect the ultimate quality and performance of the constructed pavement even though good quality materials were used (Echeverry et al. 1988, Gendell and Masuda 1988, and Low et al. 1988).

The process by which hot asphalt concrete is constructed involves two major steps. These are :

- selection of aggregate and asphalt materials, and the development of proper mix design; and
- good construction practices, including plant operation, mix transportation, and placement of the mix using proper paving and compaction equipment.

Good quality control in each of these steps is essential in producing good quality asphalt concrete pavement. A less than satisfactory performance in any of these steps can result in a pavement that will perform poorly. For an adequate contractor's quality control performance, the contractor should have a quality control program administered by qualified personnel and technicians to perform all inspection and sampling and testing activities that are necessary to attain the desired quality level, and to prevent any incorrect process that may affect the final pavement quality (Powell 1986, and Robbins 1984).

b. Asphalt Concrete Materials

an asphalt concrete pavement is only as good as the material and workmanship that goes into it. The pavement could be penalized with a shortened service life (poor performance) if the material used is of inferior quality (Kautson 1986). During mixing, asphalt cement and aggregate materials are heated and blended together in exact proportions at a hot mix plant, and transported to the paving site where the mixture is placed and compacted to the specified density. The following points are related to asphalt and aggregate materials used in the mixture's production.

1) Asphalt Cement

Asphalt is a cementitious material that varies widely in consistency from solid to semisolid at normal air temperature. When heated sufficiently it becomes a liquid with which aggregate particles are coated during the mix production. The properties of asphalt cement that are of most interest to asphalt mixture design and production are durability, adhesion and cohesion, temperature susceptibility, and hardening and aging. For proper selection of asphalt cement grade and properties, the engineer should consider the effect of construction techniques, traffic and environment on the asphalt properties, so that the proper asphalt grade is selected for the desired mixture's quality.

2) Mineral Aggregate

Aggregates, in general, are classified according to their sources. They include natural aggregate, processed aggregate, and artificial aggregate. Most highway projects use processed aggregates which have been produced by crushing natural gravel or rock. The aggregates make up 90-95 percent by weight and 75-85 percent by volume of the asphalt mix and other pavement structures layers. They provide most of the load bearing characteristics of the pavement. Consequently, asphalt pavement performance is influenced to a great degree by the choice and use of a proper aggregate quality (Asphalt Technology and Construction Practices 1983, and Thay-Ming and Jenn-Fang 1988).

Since 90 to 95 percent by weight of the asphalt mixture is aggregate, its quality will be a critical factor in the asphalt layer be a critical factor in asphalt layer performance. When aggregates meet cost and availability requirements they must then have certain properties to be considered suitable for use in hot mix asphalt pavement. In order to determine a suitable aggregate, its physical properties such as size and gradation, cleanliness, toughness, partial shape, surface texture, absorptive capacity, affinity for asphalt, and specific gravity must be determined to properly design the asphalt concrete mixture (Thay-Ming and Jenn-Fang 1988).

Aggregate gradation is an important factor which must be controlled during the construction phase. While any one of many gradations can be used to produce a satisfactory mix design, it is necessary to maintain a given gradation once the mix design is selected. When new aggregates or a new gradation is used, a new mix design must be developed. Allowing the aggregate gradation to vary beyond the control or specification limits during the mixing operation can result in problems in achieving the proper asphalt content and density in the finished pavement (Hay and Kopack 1986).

c. Aggregate Crushing Process at Material Source

Most pavement aggregates are produced from crushing gravel or rocks to make them more suitable for use in asphalt pavement mixtures. Proper crushing and screening are very important for the production of aggregates that meet the specification requirements. Thus, it is essential to thoroughly evaluate produced aggregates after crushing and screening to find out whether they meet quality and gradation requirements. Sometimes aggregates require double crushing and screening to improve their characteristics and gradation.

Prior and during mixture production, the contractor should establish a good communication channel with materials supplier, discussing with them any potential problems in maintaining strict uniformity of the quality and gradation of the aggregates to be used in the asphalt mixtures. A complete cooperation and assistance of the aggregate material supplier will be externally important in producing an asphalt concrete mixture of uniform gradation which can be accepted by the inspection team of the agency without penalty to the contractor (Jones and Scheroman 1980). Materials supplier quality control should be considered as a main factor in selecting the material sources.

d. Material Availability

The availability of the specified aggregate quality is essential in constructing asphalt pavement with the desired quality. However, in pavement project areas where low quality aggregate is available the contractor may have to find another material sources that meet the specified quality. This may result in additional expenses to the contractor in term of transportation cost, specially when the required aggregate quality source is located at a long distance from the mixing plant.

Because pavement material costs represent a high proportion of the total construction cost (Echeverry et al. 1988), an increase in the material cost may introduce a financial difficulty to the contractor affecting his decision on material's source selection, which may jeopardize the quality of the asphalt pavement.

The mixture design and job mix formula will depend upon the availability of the desired material's quality. When there is a shortag of the specified material during construction, the job mix formula will be changed due to changes in type and quality of the materials. However, continuous changing of the mixture design may result in an asphalt concrete pavement with different mixtures and subsequently with different levels of performance. Therefore, during mix design and production, the contractor must ensure that materials meeting the specified quality are available at his plant stockpiles.

Another source which may affect the availability of material is the evaluation performed by the agency of the contractor's material sources. Because of the effect that the materials have on the pavement's quality, many highway agencies usually require the contractor to submit samples of his material sources for evaluation and development of the mix design (Webb 1986). This is to ensure that good quality materials will be used in the mixture production and to permit the contractor to begin stockpiling these materials at the mixing plant. To achieve the objective of the material source evaluation, the contractor must ensure that the samples submitted are representative of the material to be furnished for the project. Furthermore, evaluation tests and procedures must be fair, reasonable and accurate; otherwise, an inaccurate decision related to material may be generated which may lead to a risk of either an approval of poor quality or a disapproval of good quality material sources.

e. The Use of Marginal Materials

An asphalt concrete pavement's materials quality is essential in achieving the desired pavement's quality. In pavement construction, the use of low quality (marginal) materials (i.e aggregate) may introduce a high risk associated with poorer pavement performance. Even though many variables (i.e traffic, environment, pavement design,...etc) affect pavement performance, it is generally accepted that the use of marginal material results in poorer pavement performance (Meyer and Hudson 1988).

In hot climate areas where ther is also heavy loaded traffic, an asphalt pavements constructed using marginal materials may be subjected to an accelerated deformation limiting its use, and makeing it a safety hazard at an early age. This is because the use of marginal material may not provide the required pavement load carrying capacity to handle the traffic it will exposed to under the conditions of a hot climate (Meyer and Hudson 1988, and Thay-Ming and Jenn-Fang 1988).

f. Mixing Plant Operations

During the construction process, there are many factors, which can alter the quality characteristics of the constructed pavement, from the source of the raw materials (aggregate and asphalt), to obtaining and mixing, paving, and testing the finished asphaltic pavement. As shown in Figure 2.1, variations in the quality of the constructed pavement can occur during the construction process in the aggregate gradation, the asphalt content or the pavement density. Each would affect the properties of the finished pavement. These variations can result from a contractor's operation, for example the aggregate stockpiling and handling process, or the mix production operations, which will affect the ultimate quality and performance of the constructed pavement even though good quality materials were used (Echeverry et al. 1988, and Gendell and Masuda 1988).

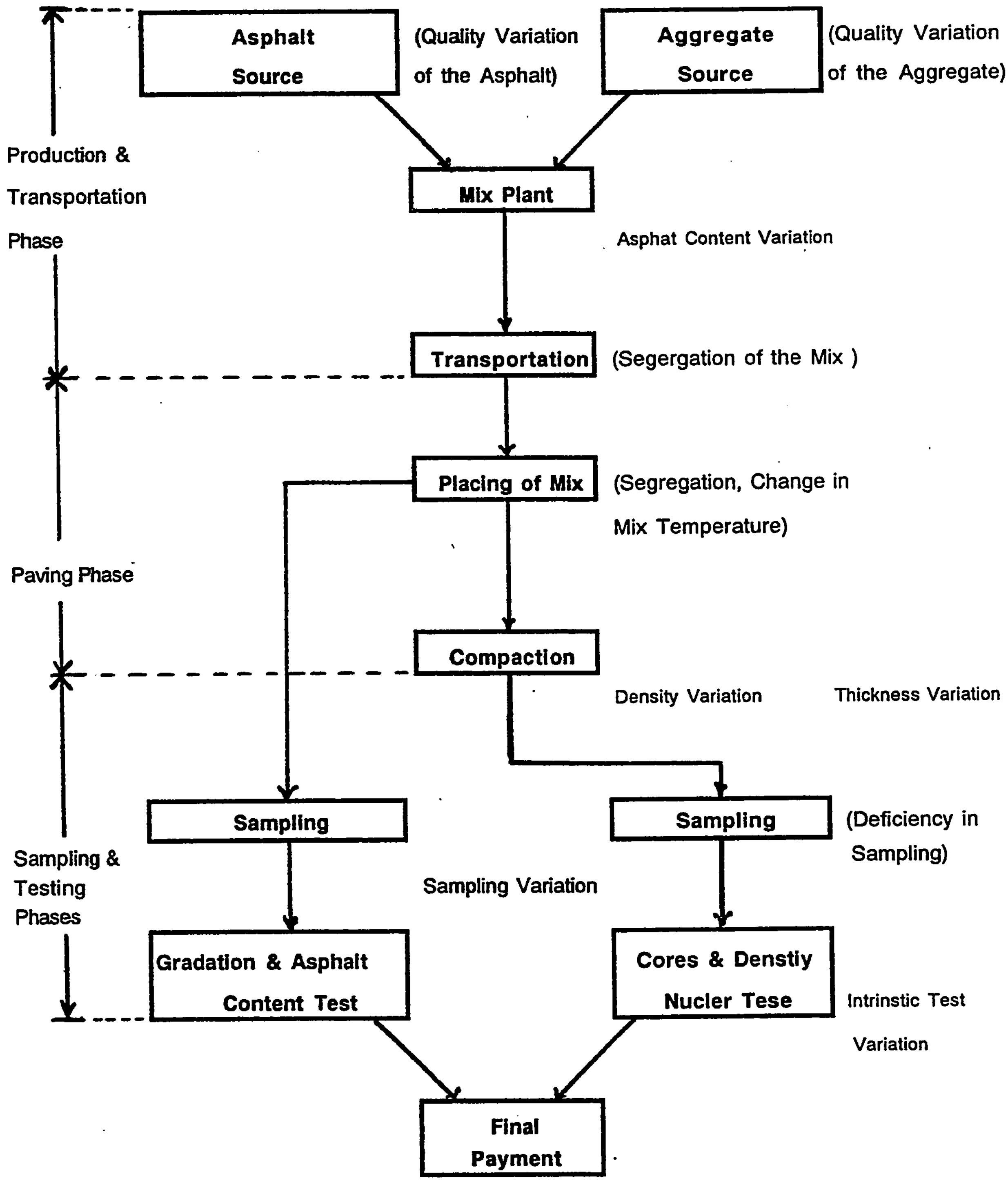


Figure 2.1- Some Sources of Quality Variation for Asphalt Concrete Pavement (Echeverry et al 1988).

1) Aggregate Stockpiling

One factor that influences aggregate quality is how it is stockpiled. Problems can be caused by poor stockpiling practices either at the quarry or at the contractor's mixing plant (Dukatz and Marek 1986). Aggregate source selection is done prior to the mix design and the material is hauled to the mixing plant site where it is to be to be incorporated into the mixture. Good stockpiling procedures are crucial to the manufacturing of a top quality asphalt hot mix. When aggregates are stockpiled properly, aggregates retain their proper gradation, where improper stockpiling procedures cause aggregate particles to segregate, resulting in variation in the gradation at different levels within the stockpile.

2) Asphalt Storage

Asphalt properties can be altered as a result of contamination and oxidation of the asphalt which may occur if improper storage of the asphalt exists. Modification of the asphalt properties can take place in the contractor's storage tanks if there is a blending of materials from different sources or accidental mixing of asphalt of different grades at the truck during asphalt transportation from the refinery to the plant's tanks (Santucci 1985).

3) Mixing Operation

Two types of mixing plants can be used in manufacturing a hot asphalt mixture. These are batch plants and drum mix plants. Regardless of the type of mix plant used, mixing time and temperature can have a dramatic effect on the consistency of the asphalt binder and on the properties and behavior of the finished mix during laydown. A careless mixing temperature and mixing time control can cause more damage to an asphalt mixture (i.e. asphalt hardening and aggregate degradation) in the mixing unit cycle, than many years of service on the constructed highway (Thay-Ming and Jenn-Fang 1988). Therefore, control of mixing time and temperature is an important factor in producing a uniformly coated homogenous mixture.

4) Variation in Asphalt Content and Aggregate Gradation

During the mixing operation, the proper asphalt content is critical to obtaining the desired void content in the compacted pavement as well as in obtaining the desired mixture properties. Assuming the mix design has been properly done, decreases from the optimum asphalt content can result in mixes that are too dry and may lead to premature raveling and cracking. Mixes containing too high an asphalt content are subjected to flushing and loss of stability. It is very necessary to control the asphalt content within very close tolerances (Hay and Kopack 1986, and Webb 1986).

Aggregate gradation is also critical for a mixture's stability and durability. It is very important to maintain a given gradation once the mix design is selected. Just as change in asphalt content can result in problems of achieving the desired void content, changes in gradation will also result in problems of achieving the desired void content. Allowing the gradation to fluctuate beyond the limits of the job mix formula can create tender mixes or mixes that are difficult to compact properly (Echeverry et al. 1988, Hay and Kopack 1986 and Webb 1986).

Because of the importance of producing asphalt concrete pavement with the required characteristics and properties, it is essential to control mixture characteristics, material, and other factors that may be responsible for variation in the mix composition. If the variations are not very well controlled substandard quality mixture may result and if used in the pavement construction, the pavement may either be rejected or accepted at a lower price.

5) Transportation of the Mix

Manufactured mixes are transported to the job site by some type of hauling equipment. Modification of asphalt mix properties can take place during the mix transportation to the paving site. Variation in the mixture temperature or aggregats segregation can occur if an inadequate mix transportation process is followed.

Using proper numbers of hauling units or trucks is a key factor in providing a steady flow of material to the paver. The required number is determined by the size of the project, the mix production rate of the plant, the length of the haul, and the expected time needed for unloading (Webb 1986).

g. Placement of Hot Mixture

The next phase of an asphalt concrete pavement construction is the placement of the hot mixture on the prepared subbase or base of the highway. If the placement of the mix is not done properly all of the effort and cost of selecting materials and designing and manufacturing the hot mixture are largely wasted (Thay-Ming and Jenn-Fang 1988).

Deviation in the asphalt pavement's quality can result during the placement, either due to the poor mechanical condition of the paver due to poor mixture conditions (i.e. temperature, mix composition,...etc).

CAUSES

PROBLEM	Fluctuating Head of Material	Feeder Screws Overloaded	Finisher Speed Too Fast	Too Much Lead Crown In Screed	Too Little Lead Crown In Screed	Overcorrecting Thickness Control Screws	Excessive Play In Screed Mechanical Connection	Screed Riding on Lift Cylinders	Screed Plates Worn Out or Warped	Screed Plates Not Tight	Cold Screed	Moldboard on Strikeoff Too Low	Running Hopper Empty Between Loads	Feeder Gates Set Incorrectly	Kicker Screws Worn Out or Mounted Incorrectly	Incorrect Nulling of Screed	Screed Starting Blocks Too Short	Screed Extensions Installed Incorrectly	Vibrators Running Too Slow
Wavy Surface — Short Waves (Ripples)	✓	✓	✓				✓	✓		✓									
Wavy Surface — Long Waves	✓	✓				✓	✓	✓					✓	✓					
Tearing of Mat — Full Width			✓						✓		✓								
Tearing of Mat — Center Streak					✓				✓		✓			✓	✓				
Tearing of Mat — Outside Streaks				✓					✓		✓	✓		✓				✓	
Mat Texture — Nonuniform	✓	✓	✓					✓	✓	✓	✓		✓					✓	✓
Screed Marks							✓												
Screed Not Responding to Correction			✓				✓	✓		✓									
Auger Shadows		✓																	
Poor Precompaction			✓					✓											✓
Poor Longitudinal Joint	✓	✓				✓		✓											
Poor Transverse Joint		✓					✓	✓		✓						✓	✓		
Transverse Cracking (Checking)																			
Mat Shoving Under Roller																			
Bleeding or Fat Spots In Mat																			
Roller Marks																			
Poor Mix Compaction																			

PROBLEM	Grade Control Mounted Incorrectly	Grade Control Hunting (Sensitivity Too High)	Grade Control Wand Bouncing on Reference	Grade Reference Inadequate	Sitting Long Period Between Loads	Improper Joint Overlap	Improper Mat Thickness for Max. Agg. Size	Trucks Bumping Finisher	Truck Holding Brakes	Improper Base Preparation	Improper Rolling Operation	Reversing or Turning Too Fast of Rollers	Parking Roller on Hot Mat	Improper Mix Design (Aggregate)	Improper Mix Design (Asphalt)	Mix Segregation	Moisture In Mix	Variation of Mix Temperature	Cold Mix Temperature
Wavy Surface — Short Waves (Ripples)	✓	✓	✓	✓						X	X			X	X	X		X	
Wavy Surface — Long Waves	✓			✓	✓			X	X	X		X	X			X		X	
Tearing of Mat — Full Width							X							X	X	X	X	X	X
Tearing of Mat — Center Streak																			X
Tearing of Mat — Outside Streaks																			X
Mat Texture — Nonuniform					✓		X			X				X	X	X		X	X
Screed Marks								X	X										
Screed Not Responding to Correction	✓						X											X	X
Auger Shadows														X	X	X			
Poor Precompaction							X			X									X
Poor Longitudinal Joint	✓	✓	✓			✓					X								X
Poor Transverse Joint											X								X
Transverse Cracking (Checking)										X	X			X	X		X	X	
Mat Shoving Under Roller										X	X	X		X	X		X	X	
Bleeding or Fat Spots In Mat														X	X		X	X	
Roller Marks										X	X	X	X					X	
Poor Mix Compaction										X	X	X	X	X	X		X	X	X

Figure 2.2: Kinds of Problems that can occure in Asphalt Concrete Layer During Construction (Scherocman, and Martenson 1984)

Figure 2.2 summarizes the various kinds of problems that can occur in an asphalt concrete layer during construction (Sacherocman and Martenson 1984). Listed in the first column is a description of various mat defects. In the remaining columns are several possible causes for each particular mat problem. Equipment related causes are marked with check marks, while the X marks indicate mix related causes.

Uniformity of placement operations is essential in producing the highest asphalt concrete quality pavement. A paver travelling at a speed that requires the mix to be supplied faster than the plant can produce it can result in the paver having to stop frequently to wait for trucks to bring more mix. The smoothness of the pavement will suffer if the wait is too long, especially on a cold day (Sacherocman and Martenson 1984). Just prior to the placement process, a mixture delivered to the project site must be within the specification requirement in terms of its composition and temperature. At the same time, the surface where the mixture is to be placed must be swept clean of loose and foreign material. Irregular surface of the base can cause irregular distribution of the mixture and a non-uniform surface will emerge from behind the screed unit (Thay-Ming and Jenn-Fang 1988).

h. Compaction

"A properly designed asphalt concrete mix will not be resistant to deformation and will not be durable unless it is properly compacted at the time of construction" (Kardhal and Koehler 1984). Of all the factors and requirements that are important to produce a durable and satisfactory pavement performance none is as important as obtaining the proper level of compaction during the construction phase. If the air void content of the asphalt concrete mix is adequate, the pavement structure will perform well under traffic even with minor variations in mix design (Hay and Kopack 1986, and Sacherocmon and Martenson 1985). Compaction with roller equipment is the most vital requirement in a achieving high level of the mixture's properties (i.e. stability, durability, fatigue resistance and impermeability), as well as adequate pavement strength to handle the traffic that it will be exposed to.

Adequate compaction of asphalt concrete mixtures is essential (Brown 1984, and Thay-Ming and Jenn-Fang 1988):

1) to prevent further significant densification under traffic, which may form ruts;
2) to provide adequate shear strength. Additional traffic generally densifies the asphalt mixture

which increases the mix stability. However, when the density is too low the initial traffic can exceed the shear strength of the mixture and cause early failure of the pavement;

3) to ensure that the asphalt mixture is essentially waterproof, by which the underlying pavement layers are protected from the adverse effect of water;
4) to prevent excessive oxidation of the asphalt binder; and
5) to reduce the void content to the point that will result in a durable and impermeable pavement that will not allow water and air to penetrate into the mixture.

Failure to properly compact the hot mix asphalt may prevent the mix from meeting one or more of the above requirements.

Prior to the compaction process, compaction rollers must be checked to determine their adequacy and capability in achieving the target density. Unnoticed equipment defects such as a vibratory roller with the vibrator operating at the wrong frequency or a pneumatic tire roller with under inflated tires may reduce the effectiveness of the equipment as well as the compaction procedures carried out by the contractor. Other variables which affect the ability of the roller to obtain the required pavement density are mixture composition and temperature, layer thickness, roller type , skill of the roller driver, rolling pattern (the operator's response in observing mix behavior and measuring densities during the compaction process), and weather conditions.

2.4- Acceptance Process Factors

An acceptance plan may be defined as an agreed-on procedure of taking and evaluating measurements for the purpose of determining the acceptability of a constructed product (Erickson 1989, and Kopack 1984). It is considered to be one of the most important components of the specification since it involves the most critical decision which has to be made by the agency to see whether to accept or reject an item of the pavement construction.

It is very important to understand that acceptance sampling and testing procedures do not assure quality in the constructed product; they only verify, within a determined probability, compliance with specified characteristics (Erickson 1984). The method used for determining acceptance must be developed through an understanding of the risks involved in acceptance decisions. Because acceptance decisions are based on test results from samples, there is always the possibility that a wrong decision will be made. Two type of wrong decision are possible: (a) acceptance of unsatisfactory work; or (b) rejection of satisfactory work. These two wrong decisions are known as the risk of the buyer (owner) and the risk of the seller (contractor). These risks must be identified and managed in developing the acceptance plan. In other words, the acceptance plan must be designed so that a contractor applying normally good control procedures to construct the specified work will run a minimum risk in having his acceptable materials (materials that meet specification) rejected. Likewise, the plans must be such that the agency can make an economical number of tests, with assurance that little risk exists that the material accepted is outside the specified limits (Burati 1986, Erickson 1989, and Powell 1986).

a. Characteristics to be Tested

When developing the acceptance plan the highway agency must determine the significant characteristics of the material or items of construction that will be measured when evaluating the material or construction item for acceptance. A significant characteristic is one that directly affects the performance of a material or item of construction; as such, it is an indicator of quality. Throughout, consideration should be given to the selection of the characteristics.

In the selection of these characteristics the specifying agency should give answers to the following questions: (a) Wat are the quality characteristics that are to be used as a basis for acceptance? (b) What properties do these characteristics measure? (c) Are all the desired properties taken into account?, and (d) How are the characteristics related? (Willenbrock and Kopac 1976). There are several characteristics which are used to measure those properties. The most commonly used characteristics to measure a pavement's properties and to determine the acceptability of an asphalt concrete pavement during or after completion of construction are: thickness, smoothness, compaction, asphalt content, asphalt properties, aggregate quality, and aggregate gradation. (Moore 1982).

b. Samples Location

Sample location can be determined either based on the agency engineer's or the inspector's judgement or by a random approach. Random sampling can eliminate the sampling bias that can be presented when the inspector uses his judgement in selecting the sample location. An experienced inspector can increase or decrease the chance that the material will meet the specification requirements by selecting a sample location where the material either looks good or bad. The variability of material can not be accurately estimated on this basis of selecting the sample location. Proper random sampling procedures eliminate this potential source of bias (Burti 1986, and Weingarten et al. 1975).

c. Acceptance Limits

The objectives of including numerical limits for a measurable quality characteristic or property in an acceptance plan are to ensure adequate product performance at economical costs and to ensure that some predetermined value that would affect performance is not exceeded (Standard Specifications for Transportation Materials and Method of Sampling and Testing, Part I, Specification 1986).

The establishment of realistic acceptance limits for the quality characteristics that are to be measured for acceptance decisions is an essential factor which is to be considered in developing the acceptance plan. These limits should be established with the capabilities of the construction materials and procedures in mind. Unrealistically high acceptance limits which can not be achieved with the current construction industry capabilities should be avoided, since this will lead to high cost in form of higher bid price, to a large percentage of the material receiving price reductions or to acceptance of a large percentage of materials that does not meet the specification requirements. (Burti 1986).

d. Acceptance Determination

The determination of the acceptability of the product is either based on an engineering judgement approach or on statistical analysis of the results from the acceptance testing program.

Under the engineering judgement approach, when test results are outside the specification, the decision whether to accept the work is left to the highway agency engineer judgement. It is up to the engineer's knowledge and experience whether the work is within "reasonably close conformity" to the specification requirement and should be accepted at full price, at lower price or should be rejected and reconstructed. Unfortunately, uniformity and consistency of engineering judgement is difficult or impossible to achieve. As a result, the contractor has no advance assurance that the acceptance terms will be interpreted fairly (Kopac 1984). This approach may result in conflicts and disagreement between the project parties.

Under the second approach, various statistical measures (i.e. mean, range, standard deviation, ... etc.) can effectively describe the quality characteristics that are desired and, by performing tests on random samples taken at the work site, it is possible to determine the extent to which the desired results have been achieved. Then depending upon the degree of compliance with the specifications, adjusted pay schedules can be used to award an appropriate level of payment to the contractor (Weed 1984, and Weingarten et al. 1975).

There are two approaches which are mostly used to determine the acceptability of pavement materials. These approaches are the Percent Defective, (PD) approach and the Percent Within Limits, (PWL) approach. In either of these approaches, the sample mean (average) and standard deviation are used with appropriate tables or computer programs to estimate the percentage of the material that is either outside PD or within PWL, the acceptance limits. Both the sample central tendency (mean) and variability (standard deviation) are combined into a single number that can be used for acceptance determination using special tables. More detail about these approaches can be found somewhere else (Burati 1986, Kopac 1984, and Weed 1984).

e. Price Adjustment System

It is essential that the constructed pavement meet the intended performance level if the agency is to get its money's worth. Work that that does not meet the specification introduces two options to the the specifying agency, either reject and reconstruct or accept at full or partial payment. A rejection decision for pavement construction is most difficult to justify and administer and not economically desirable, since it will result in a loss of resources (i.e. material, manpower, financial, ... etc). Consequently, most agencies incorporate various systems of price adjustment into their specifications so as to take into consideration the degree to which the finished constructed work conforms to requirements of the specification. If the quality of the constructed work is less than what is specified, a price reduction is applied. The more inferior the quality, the greater the reduction in the contractor's payment up to a point where the material or the constructed work is no longer accepted and must be rejected (Burati 1986, Gendell and Masuda 1988, and Weingarten et al. 1975).

Wiellanbrock and Kopac (1976) defined a price adjustment system as "a tabular, graphical, or formular representation that establishes, for a given material characteristic, the payment factors associated with estimated quality level of that characteristic". The provisions of the price adjustment recognize that material and construction at less than a desired quality level may still have significant engineering value for the highway agency. At the same time, the contractor benefits by not having to reconstruct work and receives some compensation for work that is marginally acceptable (Gendell and Masuda 1988, and Halsted and Hughes 1981). Furthermore, price adjustment provisions have other important functions for the specifying agency. Moore (1982) has indicated four main functions. These are:

1) to match payment to the serviceability or performance of the product supplied;
2) to avoid costly total rejection of a product when it is only slightly less serviceable than specified;
3) to create an incentive for the contractor or supplier to provide the quality of product desired; and
4) to provide sufficient funds to cover the cost of maintenance and future restoration of the constructed work or item to its intended design condition.

Because little data exists related material quality characteristic and their interference in performance, highway agencies often develop price adjustment factors arbitrarily. Such arbitrary factors may be applied to the expense of one or more of the contractual parties who have agreed to proceed under the specification. Sometime the price adjustment system used may over penalized substandard quality. This occurs when two or more different quality characteristics are judged independently by the payment schedule but they are actually correlated, for example aggregate gradation and asphalt content or pavement density (Echeverry et al. 1988). A better understanding of the relationship between quality characteristics and pavement performance is necessary if truly effective and economical acceptance plans, which incorporate a price adjustment system, are to be developed (Kopack 1984, Moore 1982, and Willenbrock and Kopack 1976).

Chapter III

The Survey

3.1- Introduction

The objective of this research is to identify factors affecting the quality of asphalt concrete pavement in Saudi Arabia. To achieve this objective a survey was done using a questionnaire form. Each factor listed in the questionnaire was intended to measure the degree of effect it has on the quality of asphalt concrete pavements.

3.2- Data Collection

The population under study is made up of highway contractors in the Kingdom. For this reason, the questionnaire was translated into Arabic. The questionnaire is shown in Appendix A. Because highway contractors are dispersed all over the Kingdom, a mailed questionnaire technique was used.

An official introduction letter was sent to every member of the contractor population. The letter spelt out the objective of the study and asked the contractor's senior engineer to provide the needed information related to factors affecting the quality of asphalt concrete pavement in Saudi Arabia.

3.3- Population Under Study

From the scope of the research, the population under study will all be contractors dealing with asphalt concrete pavement highway construction projects in Saudi Arabia. From the Ministry Of Communication (MOC)'s Project Executing Department, a list of highway contractors in the Kingdom was obtained with their current addresses. The list consists of seventy three (73) contractors (Appendix B). Out of these, sixty one (61) contractors are doing asphalt concrete work, the others are involved in other related works, such as concrete work, electrical work,...etc. Therefore, the total population is sixty one (61) contractor organizations. The entire population was surveyed.

3.4- Questionnaire Form

The questionnaire shown in Appendix A consists of two parts. Part I includes general information questions about the respondent's firm, including:

- Grade of the firm.
- Number of years in the pavement construction industry in Saudi Arabia.
- Number of employees.
- Average job size.
- Average job duration.

Part II concerns the factors affecting the quality of asphalt concrete pavement. The factors are subdivided into four groups, namely Managerial, Design and Specification, Construction Process, and Acceptance (Handing Over Procedure). Fifty nine (59)factors are listed. Each factor has four (4) alternative answers ranging from "Major Effect" to "No Effect". In addition, the respondent is asked to indicate those factors which most frequently occur in the Kingdom's highway pavement construction projects.

a. The factors related to Managerial are:

- Clarity of responsibilities and authorities allocation for each member participating in the project construction phase (contractors, consultants,...etc.).
- Qualification of the owner's inspection team.
- Owner team's familiarity with the project contract document, construction process, sampling and testing procedures.
- Assignment of quality control responsibility to the consultant.
- Qualification of contractors during bidding process.
- Selection of the lowest bidder to construct the project.
- Contractor's previous experience.
- Contractor's financial status during construction.
- Contractor's labor and equipment capability.
- Amount of work sub-contracted.
- Cost escalation of material, labor and equipment needed to achieve the required quality level.
- Unavailability of financial incentives for contractor to produce higher quality level.
- Delay in contractor progress payment.

b. The factors related to Design and Specifications are:

- Pavement not designed for regional conditions (e.g. soil type, material quality, traffic,...etc.).

- Design errors arising from inadequate engineer assumption inaccurate data, ...etc.
- Insufficient owner involvement during the design phase (e.g. design evaluation, review, updating design,...etc.)
- Accuracy of investigation performed on soil type encountered.
- Accuracy of data related to traffic volume, composition and expected growth.
- Climate, temperature, and its relation to materials used.
- The use of full depth asphalt concrete cross-section.
- Consistency and uniformity of specification interpretation related to aggregate quality & gradation.
- Consistency and uniformity of specification interpretation related to asphalt quality & content.
- Consistency and uniformity of specification interpretation related to mixture composition.
- Consistency and uniformity of specification interpretation related to compaction level.
- Level of technical details required to specify the desired product quality.
- Over-specifying of materials and equipment to be used, and construction techniques to be followed.
- Limitation on material source, equipment type, construction method..etc. imposed by the specification.
- Mix design does not consider the local condition (temperature and traffic...etc.).
- Mix design method used locally.
- The use of dense graded job mix formula for mixture

production.

- The use of open graded job mix formula for mixture production.
- Wide job mix formula tolerances.
- Asphalt mixture properties (e.g. stability, durability, ...etc.).

c- The factors related to Construction Process are:

- Quality control procedure (i.e. sampling and inspection) performed by the owner team during construction phase.
- Contractor's quality control for material at mixing plant stockpiles.
- Owner's evaluation of the contractor's material source.
- Availability of the specified material quality (e.g. aggregate asphalt).
- Uniformity of material at source (i.e. aggregate gradation asphalt grade).
- Aggregate crushing process at material source.
- Aggregate quality (e.g. gradation, shape, type,..etc.).
- Asphalt grade and quality.
- Variation in aggregate gradation in stockpiles, mixing, transportation and placement operation.
- Variation in asphalt content during mixture production.
- Amount of filler materials in the mixture.
- Continuous changing in mix design due to change in the nature and source of aggregate during construction.
- The use of marginal material in pavement construction in regions of hot climate and heavy traffic.
- Monitoring mixing operations (e.g. mixing time and

temperature, material feeding,... etc.)

- Lack of experienced staff (e.g. material engineer, site supervisor,..etc.) on contractor and owner team.
- Condition of road bed soil.
- Uniformity of mixture placement and compaction operations.
- Paver and roller mechanical condition and type.
- Compacting pattern used to achieve the desired density.
- Roller driver experience and skill to observe mixture behavior under roller.
- Compacting at wrong time.
- Over-compaction.

d- The factors related to Acceptance (Handing over procedure) are:

- Evaluation practices used to determine the degree of acceptability of the product.
- Qualification of the people performing acceptance procedures.
- Amount of payment deduction to penalize the contractor for for non-compliance product.
- Fairness of the method adopted by the MOC for deduction calculation.

3.5- Survey

A total of sixty one (61) questionnaires were sent to the contractor organizations. Two months later, a reminder letter, with a copy of the questionnaire, was sent to those contractors organizations who did not answer. A month later, the total number of responses received was thirty one (31) out of sixty one (61) which represents 51% of the total population. The questionnaires were then statistically analyzed to determine the degree of effect that the factors have on the quality of asphalt concrete pavements.

3.6- Responses Evaluation System

As mentioned earlier, each factor was given four possible answers. The respondent should select only one of these answers. Each answer was given a value from "0" to "3". The value "3" was given to the "Major Effect" answer, "2" to "Effect", "1" to "Some Effect", and "0" to "No Effect". In addition to indicating the degree of effect that a factor had on the pavement quality, the respondent was also asked to indicate those factors that most frequently occurred in the Kingdom. The respondent has to mark those factors using the fifth column provided in the questionnaire form.

3.7- Data Analysis

Data obtained from the questionnaires were analyzed as follows:

1) For Part (I), a cross-tabulation method was used to obtain a general description of the company (e.g. company grade, experience, ..etc.).

2) For Part (II) , a tabulation form was used to indicate the frequencies of the respondents answers (e.g. Major

Effect, Effect, Some Effect, and No Effect), and descriptive statistics such as weighted mean, standard deviation,...etc., were presented for each factor. The effect of each factor was measured in terms of its Effect Index using the following formula :

$$\text{Effect Index (EIN)} = \sum_{i=0}^{3} \frac{(A_i * X_i)}{N} * \frac{100}{3} \qquad (3.1)$$

where:

A_i = Constant expressing the weight given to each response, i=0, 1, 2, 3.

A_1 = 3 for "Major Effect"

A_2 = 2 for "Effect"

A_3 = 1 for "Some Effect"

A_4 = 0 for "No Effect"

X_i = The variable expressing the frequency of the ith response, for i = 0, 1, 2, 3 and as illustrated as follows:

X_1 = The frequency of "Major Effect" response(s).

X_2 = The frequency of "Effect" response(s).

X_3 = The frequency of "Some Effect" response(s).

X_4 = The frequency of "No Effect" response(s).

N = Number of responses

The factors are ranked according to their Effect Indexes in a table form.

3) The hypothesis test was used to test the agreement between all contractor's grades on factor's (EIN). The hypothesis test for the difference between all means was used to achieve this objective.

4) For factors that have occurred in the Kingdom, a tabulation form is used to indicate the frequency of respondents. The frequency table will indicate those factors that occurred most frequently in the Kingdom. These may need further evaluation in future studies.

5) From steps No 2 and 4, those factors having major effect, and effect degree and yet occurred in the Kingdom will be pointed out as the main factors affecting the Kingdom's pavement quality.

A qualitative analysis was conducted to determine the factors affecting the quality of the asphalt concrete pavements in Saudi Arabia. Figure 3.1 represents a graphic illustration of the research methodology.

The following chapter contains the result of the questionnaire and discussion of the various tables.

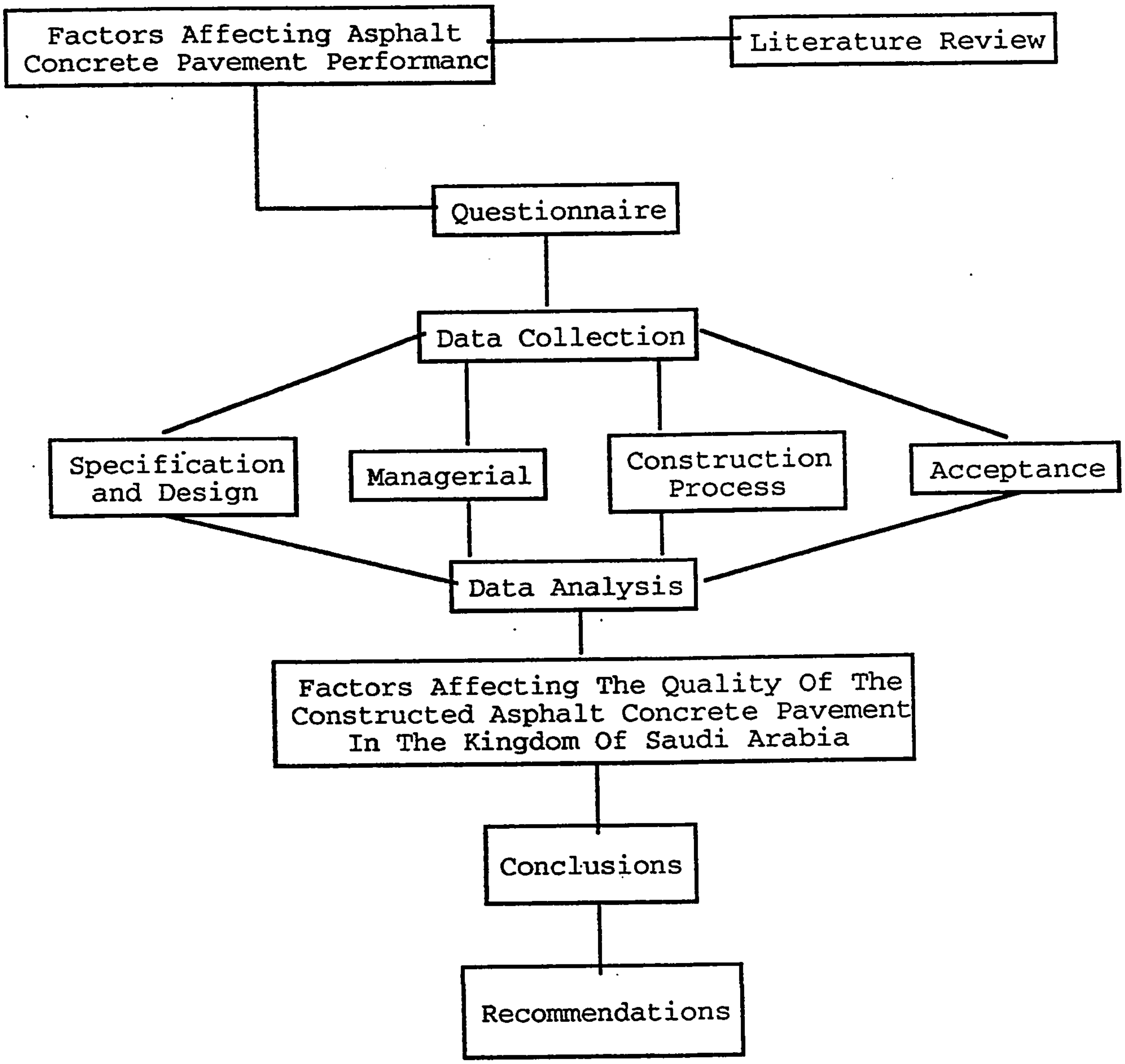


Fig. 3.1 Grahpic Illustration of the Research Methodology

Chapter IV

Data Analysis And Results

4.1- Introduction

This chapter presents the analysis of the data and the discussion of the results.

4.2- Characteristics of the Contractor

Characteristics of the contractor's are grade of the contractor, number of years in pavement construction in Saudi Arabia, number of employees, average job size and duration. Table 4.1 shows the frequency and percentage for the thirty one (31) contractors who responded .

According to the grades specified by the Ministry of Housing and Public Works, out of the thirty one (31) contractors, there were nine (9) contractors of grade one (29%), five (5) contractors of grade two (16.1%), twelve (12) contractors of grade three (38.7%), and five (5) contractors of grade four (16.1%). This classification is based on the amount of work that a contractor can perform, equipment owned, management and engineer staff,...etc. Grade one represents the largest contractor who can bid in large highway projects, where contractor's grade four represents the lowest contractor in term of work performed.

All contractors have been in the pavement construction in Saudi Arabia, industry for more than five years. The frequency table shows that 25 contractors (80.7%) have been

Table 4.1- General Information on Contractor Responses

QUESTION NO	FREQUENCY	PERCENT
1- COMPANY GRADE		
1	9	29%
2	5	16.10%
3	12	38.70%
4	5	16.10%
2- NO OF YEARS IN PAVEMENT CONSTRUCTION IN S.A (Years)		
LESS THAN 5	0	0
5 - 10.	6	19.40%
10 - 15.	10	32.30%
15 - 20	8	25.80%
MORE THAN 20	7	22.60%
3-NO OF EMPLOYEE		
LESS THAN 100	0	0
100-300	11	35.50%
300-500	10	32.40%
500-1000	4	12.90%
MORE THAN 1000	6	19.40%
4- AVERAGE JOB SIZE (MILLION OF SR)		
LESS THAN 1	0	0
5-10	0	0
10-15	2	6.50%
15-20	6	19.40%
20-50	14	45.20%
MORE THAN 50	9	29%
5- AVERAGE JOB DURATION (Years)		
LESS THAN 1/2	1	3.20%
1/2 - 1.	8	25.80%
2 - 3.	14	45.20%
MORE THAN 3	8	25.80%

in the pavement construction industry in the Kingdom for more than 10 years.

The frequency for number of employees shows that eleven contractors (35.5%) have employees between 100 to 300, ten contractors (32.4%) between 300 to 500, four contractors (12.9%) between 500 to 1000, and six contractors (19.4%) have more than 1000 employee. These levels of numbers of employees give an indication of the differences sizes of companies involved in this study.

In terms of average job size, all contractors have an average job size of more than SR 10 million per year. The frequency shows that only two contractors (6.5%) have an average job size between SR 10 and SR 15 million, six contractors (19.4%) between SR 15 million and SR 20 million, fourteen contractors (45.2%) between SR 20 million and SR 25 million, and nine contractors (29%) have more than SR 50 million . This difference in the average job sizes indicates the difference in project sizes which are being constructed . Another indication of the project sizes is shown by the average job duration. The frequencies indicate that 45.2 % (14) of the project durations are in the range of 2 to 3 years, 25.8% (8) are more than 3 years, 25.8% (8) are in the range of 6 months to 1 year, and only 3.2% (1) less than 6 months.

From the frequencies information (Table 4.1), some of the characteristics about the involved contractors are observed such as contractor's capability, experience and grade in the Kingdom's highway construction industry.

4.3- The Results

Table 4.2 presents the results of the statistical techniques for part two of the questionnaire. The table shows the frequencies, means, standard deviations and coefficients of variation (C.V) for all factors for all contractors surveyed. In Appendix D Tables 1, 2, 3 and 4 show the statistical results for grade one, grade two, grade three and grade four contractors respectively .

The mean values indicate that most of the surveyed factors either have a major effect or an effect on the quality of the finished pavement. This is because many factors can alter the quality characteristics of the final pavement from the designing and specifying phase to material processing and selection, to mix designing, mixing, placing, supervision and testing the finished asphalt pavement. This is also because of the fact that an asphalt concrete construction project is a complex process in which there are many critical places during the entire operation where something can be neglected that will affect the quality of the construction pavement (Webb 1986).

The table indicates that there is a somewhat large variation among some of the responses relating to the effect of some factors on the quality of asphalt pavements. The reason of this high variation may due to the type of this

Table 4.2- Descriptive Statistics of Research Data for All Contractors

	FACTORS	FREQUENCIES M.E	E	S.E	N.E			
		3	2	1	0	MEAN	STD	C.V %
1	Clarity of responsibilites and authority.	21	6	4	0	2.55	0.72	28.4
2	Qualification of the owner's inspection team.	19	10	2	0	2.55	0.62	24.5
3	Owners team familiarity with the construction process.	19	8	4	0	2.48	0.72	29.2
4	Assignment of QC responsibility to the consultant.	10	12	6	3	1.94	0.96	49.8
5	Qualification of contractors during bidding process.	12	13	6	0	2.19	0.75	34.2
6	Selection of the lowest bidder to construct the project.	13	8	6	4	1.97	1.08	54.9
7	Contractor's previous experience.	15	16	0	0	2.48	0.51	20.5
8	Contractor's financial status during construction.	13	14	2	2	2.23	0.84	38.0
9	Contractor's labor and equipment capability.	19	8	4	0	2.48	0.72	29.2
10	Amount of work sub-contracted.	0	10	16	5	1.16	0.69	59.2
11	Cost escalation of material, labor ...etc.	10	14	7	0	2.10	0.75	35.6
12	Financial incentives to produce higher quality level.	8	14	8	1	1.94	0.81	42.0
13	Delay in contractor progress payment.	11	14	6	0	2.16	0.73	34.0
14	Pavement not designed to the regional conditions.	26	4	1	0	2.81	0.48	17.0
15	Design errors from inaccurate assumptions, data...etc.	24	4	3	0	2.68	0.65	24.4
16	Insufficient owner involvment during design phase.	10	10	8	3	1.87	0.99	53.0
17	Accuracy of investigation on soil type.	16	15	0	0	2.52	0.51	20.2
18	Accuracy of data related to traffic volume,...etc.	17	11	3	0	2.45	0.68	27.5
19	Climate and its relation to materials used.	22	7	1	1	2.61	0.72	27.4
20	The use of full depth asphalt concrete cross-section.	12	14	2	3	2.13	0.92	43.3
21	Consistency of specification interpretation of aggregate quality.	25	6	0	0	2.81	0.40	14.3
22	Consistency of specification interpretation of asphalt quality.	19	9	3	0	2.52	0.68	26.9
23	Consistency of specification interpretation of mix composition.	22	6	3	0	2.61	0.67	25.5
24	Consistency of specification interpretation of compaction level.	20	9	2	0	2.58	0.62	24.0
25	Level of technical details to specify the desired product quality.	12	14	1	4	2.10	0.98	46.7
26	Over-specification of materials and equipment,...etc.	3	16	10	2	1.65	0.75	45.9
27	Limitation on material source selection, equipment type,...etc,	7	14	9	1	1.87	0.81	43.1
28	Mix design does not consider the local conditions.	22	8	1	0	2.68	0.54	20.2
29	Mix design method used locally.	16	12	1	2	2.35	0.84	35.6
30	The use of dense graded job mix formula for mixture production.	13	13	4	1	2.23	0.80	36.1

Table 4.2- Continue

	FACTORS	FREQUENCIES M.E	E	S.E	N.E			
		3	2	1	0	MEAN	STD	C.V %
31	The use of open graded job mix formula for mixture production.	13	15	3	0	2.32	0.65	28.1
33	Asphalt mixture properties (e.g. stability, durabilty,...ect.).	23	5	1	2	2.58	0.85	32.8
34	QC procedure performed by the owner team during construction.	21	7	3	0	2.58	0.67	26.0
35	Contractor's QC for material at mixing plant stockpiles.	13	10	8	0	2.16	0.82	38.0
36	Owner's evaluation of the contractor's material source.	11	11	7	2	2.00	0.93	46.5
37	Availability of the specified material quality.	24	6	1	0	2.74	0.51	18.8
38	Uniformity of material at source.	18	12	1	0	2.55	0.57	22.3
39	Aggregate crushing process at material source.	17	8	3	3	2.26	1.00	44.2
40	Aggregate quality (e.g. gradation, shape, type,...etc.).	26	4	1	0	2.81	0.48	17.0
41	Asphalt grade and quality.	17	12	1	1	2.45	0.72	29.5
42	Variation on aggregate gradation in stockpiles, mixing,...etc.	13	12	5	1	2.19	0.83	38.0
43	Variation on asphalt content during mixture production.	16	10	4	1	2.32	0.83	35.8
44	Amount of filler materials in the mixture.	25	5	0	1	2.74	0.63	23.0
45	Continuous changing in mix design.	13	9	4	5	1.97	1.11	56.4
46	The use of marginal material.	19	12	0	0	2.61	0.50	18.9
47	Monitoring mixing operations.	15	13	3	0	2.39	0.67	28.0
48	Lack of experienced staff on contractor and owner team.	21	9	1	0	2.65	0.55	20.8
49	Condition of road bed soil.	19	12	0	0	2.61	0.50	18.9
50	Uniformity of mixture placement and compaction operations.	17	11	3	0	2.45	0.68	27.5
51	Paver and roller mechanical condition and type.	13	16	2	0	2.35	0.61	25.8
52	Compacting pattern used to achieve the desired density.	12	14	5	0	2.23	0.72	32.2
53	Roller driver experience to observe mixture behavior.	15	11	5	0	2.32	0.75	32.2
54	Compacting at wrong time.	22	7	2	0	2.65	0.61	23.0
55	Over-compaction.	14	11	6	0	2.26	0.77	34.2
56	Evaluation practices used for product acceptance.	7	14	9	1	1.87	0.81	43.1
57	Qualifiction of the people performing acceptance procedures.	17	9	4	1	2.35	0.84	35.6
58	Amount of payment deduction for non-compliance product.	6	12	6	7	1.55	1.06	68.4
59	Fairness of the method adopted by the MOC for deduction.	6	14	6	5	1.68	0.98	58.4

study which is an opinion survey. The high C.V value could also be due to the difference in the experience and background of the respondents who used their judgment in answering the questions.

4.4- The Effect Index

The effect of each factor on the quality of an asphalt concrete pavement is measured on the basis of the calculated Effect Index (EIN). The factors are subdivided into four groups, namely, a) Managerial, b) Design and Specification, c) Construction Process, and d)Acceptance (Handing Over Procedures). The calculated EIN of the factors is ranked and shown in Table 4.3.

In the following discussion the factors are subdivided into categories according to the Effect Index. Factor having EIN values range from 100% to 83%, are considered to have a major effect; values less than 83% but greater than or equal to 50% are considered to have an effect; values less than 50% but greater than or equal to 17% are considered to have some effect; and values less than 17% are considered to have no effect on the quality of the pavement.

4.4.1- Managerial Factors

Table 4.4 shows the Managerial related factors ranked according to their calculated EIN, with their degree of effect on the pavement's quality. Figure 4.1 shows the histogram of these factors. The following points discuss the main factors.

Table 4.3 - Effect Index - All Contractors

	FACTORS	Effect INDEX
	A - MANAGERIAL	
1	Clarity of responsibilites and authority.	84.95 %
2	Qualification of the owner's inspection team.	84.95 %
3	Owners team familiarity with the construction process.	82.80 %
7	Contractor's previous experience.	82.80 %
9	Contractor's labor and equipment capability.	82.80 %
8	Contractor's financial status during construction.	74.19 %
5	Qualification of contractors during bidding process.	73.12 %
13	Delay in contractor progress payment.	72.04 %
11	Cost escalation of material, labor ...etc.	69.89 %
6	Selection of the lowest bidder to construct the project.	65.59 %
4	Assignment of QC responsibility to the consultant.	64.52 %
12	Financial incentives to produce higher quality level.	64.52 %
10	Amount of work sub-contracted.	38.71 %
	B- DESIGN AND SPECIFICATION	
14	Pavement not designed to the regional conditions.	93.55 %
21	Consistency of specification interpretation of aggregate quality.	93.55 %
15	Design errors from inaccurate assumptions, data...etc.	89.25 %
28	Mix design does not consider the local conditions.	89.25 %
19	Climate and its relation to materials used.	87.10 %
23	Consistency of specification interpretation of mix composition.	87.10 %
24	Consistency of specification interpretation of compaction level.	86.02 %
33	Asphalt mixture properties (e.g. stability, durabilty,...ect.).	86.02 %
17	Accuracy of investigation on soil type.	83.87 %
22	Consistency of specification interpretation of asphalt quality.	83.87 %
18	Accuracy of data related to traffic volume,...etc.	81.72 %
29	Mix design method used locally.	78.49 %
31	The use of open graded job mix formula for mixture production.	77.42 %
30	The use of dense graded job mix formula for mixture production.	74.19 %
32	Wide job mix formula tolerances.	72.04 %
20	The use of full depth asphalt concrete cross-section.	70.97 %
25	Level of technical details to specify the desired product quality.	69.89 %

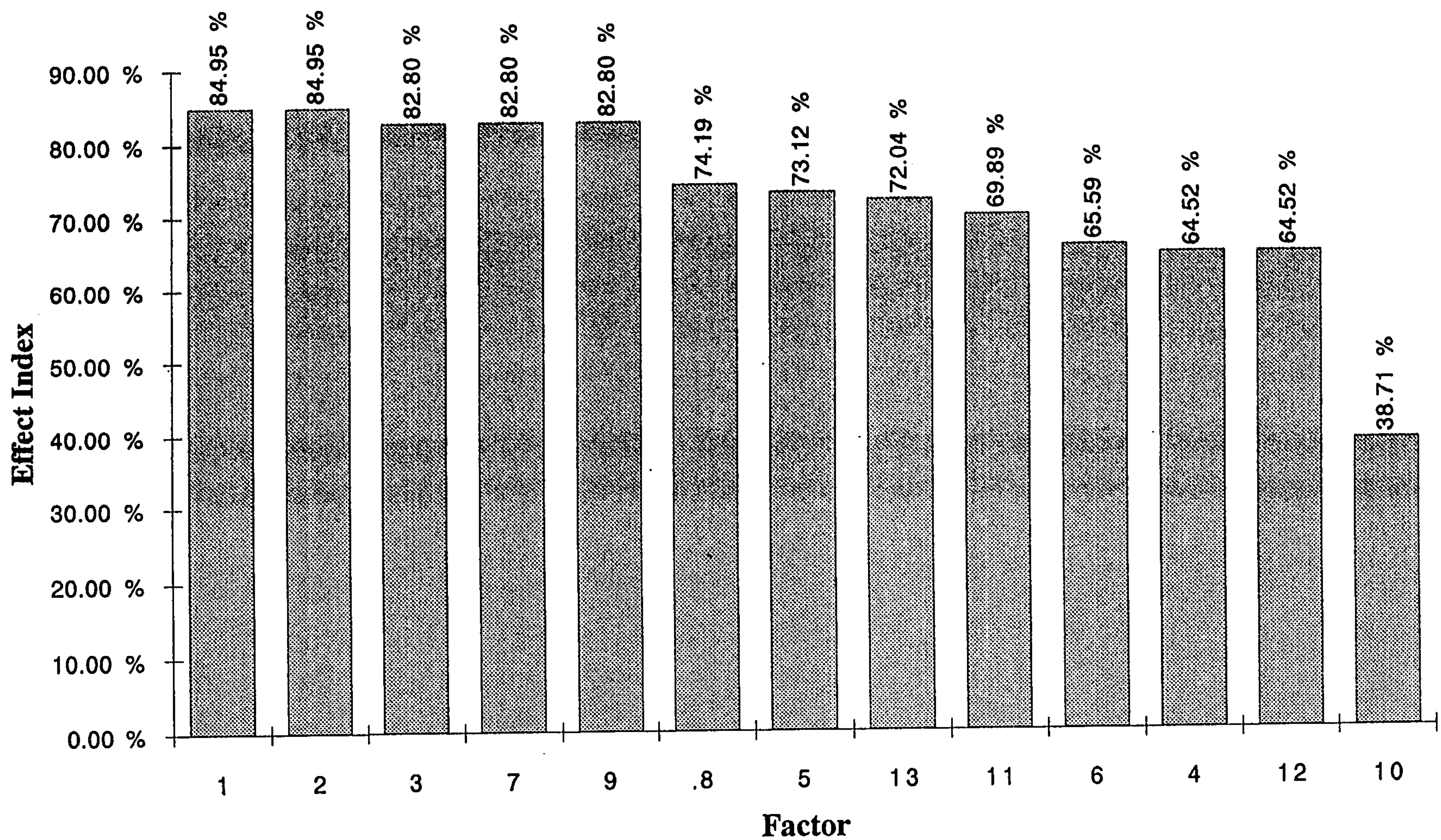
Table 4.3- continued

	FACTORS	Effect INDEX
16	Insufficient owner involvment during design phase.	62.37 %
27	Limitation on material source selection, equipment type,...etc,	62.37 %
26	Over-specification of materials and equipment,...etc.	54.84 %
	C - CONSTRUCTION PROCESS	
40	Aggregate quality (e.g. gradation, shape, type,...etc.).	93.55 %
44	Amount of filler materials in the mixture.	91.40 %
37	Availability of the specified material quality.	91.40 %
54	Compacting at wrong time.	88.17 %
48	Lack of experienced staff on contractor and owner team.	88.17 %
49	Condition of road bed soil.	87.10 %
46	The use of marginal material.	87.10 %
34	QC procedure performed by the owner team during construction.	86.02 %
38	Uniformity of material at source.	84.95 %
50	Uniformity of mixture placement and compaction operations..	81.72 %
41	Asphalt grade and quality.	81.72 %
47	Monitoring mixing operations.	79.57 %
51	Paver and roller mechanical condition and type.	78.49 %
53	Roller driver experience to observe mixture behavior.	77.42 %
43	Variation on asphalt content during mixture production.	77.42 %
55	Over-compaction.	75.27 %
39	Aggregate crushing process at material source.	75.27 %
52	Compacting pattern used to achieve the desired density.	74.19 %
42	Variation on aggregate gradation in stockpiles, mixing,...etc.	73.12 %
35	Contractor's QC for material at mixing plant stockpiles.	72.04 %
36	Owner's evaluation of the contractor's material source.	66.67 %
45	Continuous changing in mix design.	65.59 %
	D - ACCEPTANCE (HANDING OVER PROCEDURE)	
57	Qualifiction of the people performing acceptance procedures.	78.49 %
56	Evaluation practices used for product acceptance.	62.37 %
59	Fairness of the method adopted by the MOC for deduction.	55.91 %
58	Amount of payment deduction for non-compliance product.	51.61 %

Table 4.4 Managerial Factors and their Degree of Effect on the Quality of Asphalt Concrete Pavement (from table 4.3)

DEGREE OF EFFECT	FACTOR #	FACTORS	EFFECT INDEX
MAJOR EFFECT	1	Clarity of responsibilites and authority.	84.95 %
"	2	Qualification of the owner's inspection team.	84.95 %
EFFECT	3	Owners team familiarity with the construction process.	82.80 %
"	7	Contractor's previous experience.	82.80 %
"	9	Contractor's labor and equipment capability.	82.80 %
"	8	Contractor's financial status during construction.	74.19 %
"	5	Qualification of contractors during bidding process.	73.12 %
"	13	Delay in contractor progress payment.	72.04 %
"	11	Cost escalation of material, labor ...etc.	69.89 %
"	6	Selection of the lowest bidder to construct the project.	65.59 %
"	4	Assignment of QC responsibility to the consultant.	64.52 %
"	12	Financial incentives to produce higher quality level.	64.52 %
SomeWhat Effect	10	Amount of work sub-contracted.	38.71 %

Figure 4.1 - Histogram - Managerial Factors



a) Clarity of responsibilities and authorities:

Table 4.4 shows that the quality of an asphalt concrete pavement is affected to a great degree by the clarity of the responsibility and authority allocation of each member participating during the construction phase (i.e. Engineers, Consultants, Inspectors, Contractors,..etc.). The EIN value for this factor is 84.95%.

Achieving quality on the construction project is a team effort. During the construction phase, numerous personal interactions are involved out of which adverse relationship can evolve. This can jeopardize the quality of the finished work. It is essential to create team work between the parties during the construction phase. The contract document which shapes the relationship between the parties must describe in a clear manner the responsibilities and authorities of each member participating during the construction phase. Each member must know what is expected from him, where he fits into the construction process and his relationship with the other team members. With this clear definition of responsibilities, construction administration is enhanced, mutual respect is developed, conflict is minimized ,cooperation between team members is created, and more effort is focused on constructing the project at the lowest cost, consistent with the quality desired.

b) Owner inspection team:

The success or failure of the qualify of a construction project depends highly on the roles the inspector plays during the construction phase (Tenah 1986). The owner's inspection team qualification has also been shown to have a major effect on the quality of the constructed pavement as indicated by their EIN values in Table 4.4. The inspection team is expected to administer the construction with fairness and firmness with the assurance that the MOC receives acceptable work for the funds expended. According to the MOC's Highway Construction Manual, the inspection team has the following responsibilities to carry out:

1) Fully inspecting the construction activities, only accepting work that is completed and in strict compliance with the specifications.
2) Monitoring contractor's performance and ensuring that the contractor carries out his responsibilities.
3) Preparing a Monthly Progress Report showing all work performed, measurements, test results and recommendation for monthly payments.

Qualification and experience of the inspection team are essential to performing these required responsibilities and to making sure that good quality materials are incorporated into the pavement and that good construction practices are followed to achieve a good end product. Furthermore, test results on pavements require proper interpretation by a qualified and experience inspector who will know for instance when to discard a test, to repeat a test or to reject the work. Variable or inconsistent inspector interpretations due to lack of experience may result in conflict and claims between the contracting parties.

c) Contractor's Experience and Capability:

A contractor's experience and labor and equipment capability have been shown to have an effect on the quality as indicated by EIN values (82.8%) in Table 4.4. These factors are two of the main resources of the contractor in efficiently performing the construction operations, and in developing better and more economical ways to accomplish the work. They play a major role in asphalt concrete pavement project execution. They are of special importance to the Kingdom since it encompasses different areas, i.e. sand dune areas, mountainous areas, and sabkha areas, which require special experience and capability to meet the design, specification and construction challenges in pavement construction in these areas (Highway Design and Construction 1988).

d) Selection of the lowest bidder to construct the project:

It is evident that the selection of the lowest bidder to construct the project does not have a major effect on quality (its EIN value is 65.59%). During the bidding process, the Ministry forms a technical committee charged with the task of checking the validity of and compliance with specification and contract documents of the lowest few bidders. The procurement law for public projects states that the project must be awarded to the lowest qualified bidder. This law is devised to achieve fairness between contractors and to have lower bids through increasing the number of competitive contractors. However, such practice can limit the Ministry's control over the awarding system, and hamper the Ministry in selecting the qualified contractor. As a result the project quality may suffer. When the selected contractor bid is under bid, the contractor may try to take short cuts or reduce the quality of his work in order to reduce his cost. " The concept of construction at the lowest price may sometimes place Quality in a secondary role" (Sandbery 1987). In order to reduce the risk of awarding the contract to an unqualified contractor, prequalification of all competitors must be done during the bidding process.

e) Amount of work sub-contracted:

Among the Managerial factors listed in Table 4.4, the factor related to the amount of work sub-contracted has the lowest EIN value (38.71%). This value indicates that the amount of work sub-contracted has some effect on the quality. In highway construction projects, the sub-contracting system is very well controlled by the Ministry. According to the Ministry's Highway Construction Manual, the contractor must perform with his own organization work amounting to not less than fifty (50) percent of the original contract amount. For any work to be sub-contracted, the contractor is required to submit a request in writing to the Ministry. He is further required to present evidence that the proposed sub-contractor is fully qualified to do the work by proving information regarding the sub-contractor's experience, qualification, equipment capability, type of activities performed,...etc.

After an investigation and review, the Ministry may approve or disapprove the request for sub-contracting. For any work sub-contracted the prime contractor is solely responsible for all work performed by the sub-contractors.

Table 4.4 shows the other Managerial factors with their degree of effect on the pavement's quality.

4.4.2- Design and Specification Factors

Table 4.5 shows the design and specification related factors ranked according to the EIN values. Figure 4.2 shows the histogram of these factors.

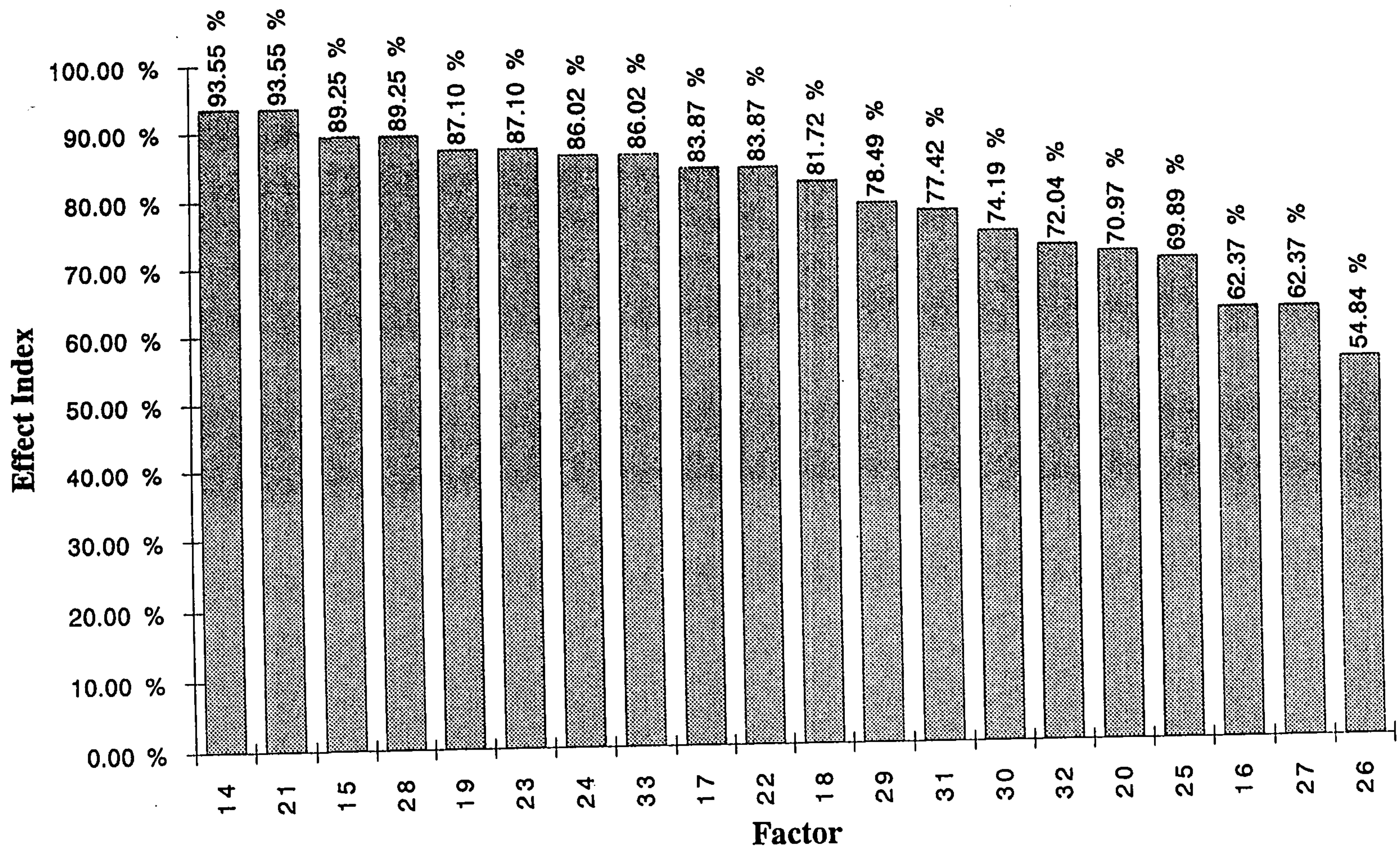
a) Pavement design

Pavement that is not designed to the regional conditions (i.e. traffic, climate,...etc.), has the highest EIN value (93.35%). The structural design of the pavement has an overriding influence on the performance of the pavement regardless of how the construction process and quality control are carried out during the construction phase. It makes no difference how carefully the construction is performed if the design is defective. The pavement design process consists of finding an appropriate combination of materials and layer thickness which mitigate various forms of distress induced in the pavement from traffic and environmental related factors (Monismith et al. 1985). Such process requires accurate traffic, climate and soil type data and reliable design procedure in order to select materials characteristics and thickness to provide an adequate pavement

Table 4.5 Design and Specification Factors and their Degree of Effect on the Quality of Asphalt Concrete Pavement (from table 4.3)

DEGREE OF EFFECT	FACTOR #	FACTORS	EFFECT INDEX
MAJOR EFFECT	14	Pavement not designed to the regional conditions.	93.55 %
"	21	Consistency of specification interpretation of aggregate quality.	93.55 %
"	15	Design errors from inaccurate assumptions, data...etc.	89.25 %
"	28	Mix design does not consider the local conditions.	89.25 %
"	19	Climate and its relation to materials used.	87.10 %
"	23	Consistency of specification interpretation of mix composition.	87.10 %
"	24	Consistency of specification interpretation of compaction level.	86.02 %
"	33	Asphalt mixture properties (e.g. stability, durabilty,...ect.).	86.02 %
"	17	Accuracy of investigation on soil type.	83.87 %
"	22	Consistency of specification interpretation of asphalt quality.	83.87 %
EFFECT	18	Accuracy of data related to traffic volume,...etc.	81.72 %
"	29	Mix design method used locally.	78.49 %
"	31	The use of open graded job mix formula for mixture production.	77.42 %
"	30	The use of dense graded job mix formula for mixture production.	74.19 %
"	32	Wide job mix formula tolerances.	72.04 %
"	20	The use of full depth asphalt concrete cross-section.	70.97 %
"	25	Level of technical details to specify the desired product quality.	69.89 %
"	16	Insufficient owner involvment during design phase.	62.37 %
"	27	Limitation on material source selection, equipment type,...etc,	62.37 %
"	26	Over-specification of materials and equipment,...etc.	54.84 %

Figure 4.2 - Histogram - Design & Specification



performance for the required design life.

Within the Kingdom there are special traffic and environmental (Temperature and Soil type) conditions which do not allow the use of design criteria and standards that are developed based on other countries's experience (Pavement Rutting in the Kingdom of Saudi Arabia). Pavement design which is based on the experience of other countries and not properly adjusted to reflect regional conditions has been considered to be one of the causes for pavement rutting in the Kingdom(Dubaib et al. 1986). Dr.Sterling (1986) indicated that the process of transferring western design methods and standards to the Arabian Gulf has incurred many cases of road pavements that were too expensive and yet failed too early.

An example of pavement design which is based on the experience of other countries is the use of full depth asphalt concrete pavement (The EIN value for this factor is 70.97%). Due to the increase in the traffic volume and the types of vehicles using the Kingdom road network in the seventies, the MOC re-evaluated the structural design of pavements in which full depth asphalt concrete layers up to 25 cm in thickness were used for primary roads. Limitations of the full depth asphalt pavement became evident when the roads were subjected to high axle loads coupled with extreme temperature conditions. Some of the primary roads designed by the full depth concept developed rutting in their asphalt layers. After an investigation of the causes, the structural design was revised eliminating full depth paving. The new MOC pavement design limited asphalt concrete layer thickness to 15 cm. The remaining required thickness is made up of crushed aggregate course and/or angular sub-base materials. Currently the Ministry is using the newly revised Guide for Design of Pavement Structure, published in 1406 H (1986) by the American Association of State Highway and Transportation Officials (AASHTO) (Highway Design and Construction 1988).

It is very important to re-evaluate any design method or standard, prior to being adopted, for modification to reflect the Kingdom's special conditions. Using a rational pavement design method which is based on local conditions can result in substantial saving of construction and maintenance costs.

b) Asphalt Concrete Pavement's Specification

The adequacy of the specification is an important factor in determining the final quality that is achieved on a construction project. Materials quality to be incorporated into the project, quality of workmanship and desired characteristics of the finished work are included in the Technical Specification part of the Bid/Contract Documents. Poor specifications often lead to inconsistent interpretations, misunderstanding and claims between the contracting parties (Gendell and Masuda 1988, and Jackson 1990).

Among the most important materials characteristics that are specified for asphalt concrete mixture are aggregate quality, asphalt grade, mix composition (i.e aggregate gradation and asphalt content), and compaction level. These characteristics play a significant role in the quality and performance of asphalt concrete pavements. As shown in table 4.5, these factors have major effects on the quality of the constructed asphalt concrete pavement.

1. Aggregate Quality:

Specification for aggregate quality is among the factors which have the highest EIN value (93.55%). Aggregate makes up 90 - 95 percent of hot mix weight and provides most of the load bearing characteristics. Consequently, pavement performance can be greatly influenced by the quality and uniformity of the aggregate used. The angularity, durability and chemical nature of the aggregate has a significant effect on the properties of the mix in resisting permanent deformation (Dubaib et al. 1986). Several studies indicate that the Specification requirement for fine aggregate in Saudi Arabia can allow contractors to use (1.) aggregate that have undergone little crushing or (2.) natural sand (dune sand) in asphalt concrete mix production. Since dune sand has a significant amount of well rounded and sub-rounded particles, and because this material has a very low internal friction comparable to crushed sand, the use of this material in mix production would tend to produce mixes with lower mechanical strength. Under heavy traffic loading conditions, pavement distress (i.e. permanent deformation) can develop because of the low mix mechanical strength. (DAR-ALhandasah 1986, Khan et al. 1986, and Pavement Rutting in the Kingdom of Saudi Arabia)

2. Mix Composition:

Table 4.5 shows that mix composition (i.e. aggregate gradation and asphalt content) has a major effect on the quality of asphalt concrete pavements. (EIN value is 87.10%). Both aggregate gradation and asphalt content play a great role in providing the necessary mixture propertied, (i.e. stability, durability,...etc.). The combination of the aggregate will allow sufficient voids to accommodate the proper asphalt film thickness on each particle, and still allow sufficient air voids to provide for thermal expansion of the asphalt and mix particles. Severe rutting with a collapse of the bearing capacity occurs for any asphalt concrete layer if the air voids of the layer fall below 1.5%. It is necessary to avoid reaching a low air void content under the highest degree of compaction from traffic. Most of the researches on pavement rutting in the Kingdom have recommended the use of aggregate gradation which is relatively on the coarse side to ensure enough free air voids during the pavement's service life. (DAR-ALhandasah 1986, Khan et al. 1986, and Pavement Rutting in the Kingdom of Saudi Arabia)

The proper asphalt content is critical in obtaining the desired void content in the compacted mix, and affects durability, flexibility, fatigue resistance, stability and susceptibility to moisture damage (Hay and Kapac, 1986). The optimum asphalt content of a mix is highly dependent on aggregate gradation and absorptiveness. The finer the mix gradation, the larger the total surface area of the aggregate and the greater the amount of asphalt required to uniformly coat the particles. In hot climate conditions, as is the case in the Kingdom, a dense graded mix with high asphalt content may produce mixtures which are susceptible to deformation. This is because, with dense gradation, the high asphalt content may act as though greased at high temperature which will reduce the internal friction of the asphalt concrete layer (DAR-ALhandasah 1986, and Pavement Rutting in the Kingdom of Saudi Arabia). With coarse gradation the quantity of asphalt can be reduced since coarse gradations have less total aggregate surface area, which demands less asphalt. The effect of aggregate gradation and asphalt content will be further discussed under the mix design related factors.

3. Compaction Level

Specification related to compaction level has an EIN value of 86.02%. To resist the effect induced on the pavement by the traffic and environment, an asphalt concrete pavement must have several properties such as stiffness, fatigue resistance, permanent deformation resistance, and durability. Compaction has been identified as probably the most vital requirement in achieving a high level of these properties (Bell et al. 1984, Hay and Kapac 1986, and Webb 1986). This may be due to the interrelationship between these properties and the air void content. The latter is highly dependent on the compaction requirements.

The MOC's general specifications require an asphalt pavement to be compacted to at least 96% of the Marshall

Laboratory density. For primary roads, a minimum of 92% and 93% of the Maximum Specific Gravity is required for the asphalt concrete base and wearing coarse layer respectively (Highway and Construction 1988). Most of the researches on the causes pavement rutting in the Kingdom have recommended the use of the Maximum Theoretical Specific Gravity as a means for pavement density measurements. Some of the researches have indicated that the use of the daily Marshall Laboratory density as a reference for pavement density measurement has the major disadvantage of not giving the real void ratio of the mix which is one of the most important characteristics for ensuring that the mix actually used on the site does have the properties that were originally sought for in the preliminary laboratory mix design (DAR-ALhanasah 1986, Khan et al. 1986, and Preventive Maintenance for Saudi Arabian Road System 1984).

4. Asphalt Quality

Specifications for asphalt quality have been shown to have a lower EIN value (83.87%) than for aggregate quality, mix composition and compaction level (see Table 4.5). However, this is still a high value which indicates the importance of asphalt quality with regard to the quality of asphalt concrete pavements. The physical properties of the asphalt cement used are important and have significant effects on the properties of the mixture. For instance, a very hard grade of asphalt will result in brittle mixes with low temperature cracking, while a softer grade in hot climate conditions may result in tender mixes which will give rise to permanent deformation, and bleeding when subjected to heavy truck traffic (Dubabe et al. 1986). Thus asphalt grade selection should be based on the traffic and climate conditions which the pavement will be exposed to.

Asphalt cement grade 60 - 70 penetration is the bitumen being usedin the Kingdom for asphalt concrete pavement construction. This grade, given the Kingdom's hot climate, has been considered by many researches as too soft bitumen for primary roads and thus as one of the main reasons of pavement failure in the Kingdom (Pavement Rutting in the Kingdom of Saudi Arabia, and Preventive Maintenance for Saudi Arabian Road System 1984). Grade 60-70 bitumen has a softening point between 49-54 Degrees Centigrade which is far below possible surface temperature, which might reach up to 70 Degrees Centigrade. Since the filler content will increase the softening point of the bitumen-filler mortar, special requirements for filler to asphalt ratio have recently been adopted by the MOC for primary roads. A filler to asphalt ratio of 1 to 1.5 is targeted at the optimum asphalt content to achieve a softening point exceeding 75 Degree Centigrade (Highway Design and Construction 1988).

As the bitumen is generally the weakest part of the asphalt concrete, especially under hot climate conditions, it must be the aim to improve the thermoelastic properties of the binder. Most of the researches studying the causes of pavement rutting in the Kingdom have recommended the use of either a harder asphalt grade (i.e. 40-50 penetration) or modified asphalt cement (i.e. additive material such as polymer added to the 60-70 asphalt grade), to improve the thermoelastic properties of the mix (i.e. the softening point). (Dubabe et al. 1986, Khan 1986, Pavement Rutting in the Kingdom of Saudi Arabia, and Preventive Maintenance for Saudi Arabian Road System 1984)

c) Design Errors and Owner Involvement During the Design Phase:

Other design related factors affecting the quality of asphalt concrete pavements are design errors from inaccurate assumption (the EIN value is 89.25%) and insufficient owner involvement during design phase (the EIN value is 62.37%). Engineering errors in assumption or design data are more serious and may not be discovered until the project is completed and used at which time corrections are costly (Burgess, 1988). AL-Jarallah and Mohan (1986) have indicated that most design errors, in public projects, are caused by design teams who do most of their work abroad with little or no consideration of the local conditions. These design errors have resulted in higher construction cost, time delays (from change of orders) and low project quality, which increases the maintenance cost during the project,s service life.

Owner involvement during the design stage must be sufficient to ensure good quality design and make sure that data, design standards and methods are applicable to the Kingdom's special traffic and environmental conditions (AL-Musaid 1990).

d) Mix Design:

In hot mix asphalt paving mixture, mix design preparation consists of obtaining a proper aggregate gradation and asphalt content to ensure sufficient strength and a proper air void content in the compacted pavement. The relative proportion of these materials as well as their quality determines the mixture's properties (i.e. stability, durability,..etc.) and ultimately how the mixture will perform as a finished product during its service life. As shown in Table 4.5, mix design which does not consider the local conditions (i.e. traffic, and climate) has a major effect on the quality of asphalt concrete pavements. The EIN value for this factor is 89.25%. This indicates the importance of designing the mixture according to the local conditions for satisfactory performance throughout the pavement's service.

1. Asphalt Concrete's Mixture Design:

Both traffic and climate are very important parameters in the development of the pavement structural design. In the Kingdom, there are special traffic and climate conditions which have to be considered unique in the world. Such conditions are far more severe than those encountered in most western countries, which make the transfer of mix design technology and experience from developed countries a tricky and often dangerous practice (AL-Dhalaan. M, Pavement Rutting in the Kingdom of Saudi Arabia, and Sterling 1986).

In the Kingdom, asphalt concrete mixes have always been prepared using the Marshall mix design method. In the early sixties, various types of grading were specified for bituminous mixtures which were based on the experience of the Ministry's consultants and the availability of materials on site. Due to pavement durability problems, the General Specification was revised in 1972. Densely graded wearing and a base course mixture were specified along with the use of natural sand. The minimum requirement for crushed sand in fine aggregate was set at 25%. In other words, natural sand can be used up to 75% by weight of the crushed fine aggregate. For asphalt content, the policy of adding as much asphalt as possible was promoted. Because of the tremendous increase in the volume and type of traffic using the Kingdom's highway network, early rutting in some of the newly constructed asphalt concrete pavements have resulted (Highway Design and Construction 1988).

Traffic loading and climate conditions have been identified as contributing factors which have accelerated the rate of the development of rutting. The main causes of pavement rutting were identified as being more related to the properties of the materials and mix design procedure used than load and climate alone (DAR-ALhandasah 1986, and Khan et al. 1986). For instance the major cause of rutting in the Dhahran - Abqaiq road was identified as the inadequacy of the specified mix for climate conditions, i.e. high temperature, and loading (Al-Dalaan. M).

The combined effect of the use of natural sand (dune sand) and high asphalt content in a dense graded mix will tend to produce mixtures which are susceptible to deformation under conditions of the hot climate and heavy traffic (DAR-ALhandasah 1986, and Pavement Rutting in the Kingdom of Saudi Arabia). With dense grading and a large quantity of natural sand (i.e. dune sand), voids in the Mineral Aggregate (VMA) are usually low. Asphalt concrete mixes become more prone to distress as their VMA decreases. Low VMA values generally indicate that a mix will be deficient in either asphalt content or air void content. Because dense graded mixes usually have low air void content, low VMA can cause a further reduction in the air void content in the asphalt concrete layer due to the traffic compaction. tis will cause flushing, loss of stability and severe rutting with a collapse of the bearing capacity of the asphalt concrete layer (DAR-ALhandasah 1986, Pavement Rutting in the Kingdom of Saudi Arabia, and Sterling 1986).

Because VMA is directly related to aggregate gradation, most of the researches done on pavement rutting in the Kingdom have recommended the substitution of an open gradation for the dense gradation with a maximum amount of coarse aggregate with minimum VMA to ensure sufficient air void content in the pavement at the highest degree of compaction from traffic. (DAR- ALhandasah 1986, and Khan et al. 1986).

It has been concluded that mix design is the area in which it would be possible to avoid the development of asphalt concrete pavement distress which has occurred in the Kingdom's highway pavements. Without any modifications, future construction will run the risk of exhibiting the same distress. Mixture properties to some extent can be changed to suit the special traffic and climate conditions of the Kingdom by changing or modifying the mixture's composition (DAR-ALhandasah 1986, Dubabe et al 1986, Khan et al. 1986, and Preventive Maintenance in the Saudi Arabian Road System 1984). Recently, new specifications for primary roads has been adopted by the MOC. Both asphalt concrete base and wearing courses are now composed of a more open and coarser aggregate grading with minimum VMA to achieve higher voids content (Highway Design and Construction 1988).

2. Mix Design Method:

The mix design method used locally (Table 4.5) has an EIN value of 78.49%. Mahboub (1990), and Hay and Kopac (1986) have stated in their articles that current methods of mix design are being used beyond what they were developed to do. Current mix design procedures were developed based on specific conditions that no longer apply to some of the current requirements. Gross axle weight and tire pressure are frequently much higher today than they were just a few years ago. "An improved method of mix design is needed to address today's complex problems of heavy loads, high tire pressure and new material" (Mahboub 1990).

In the Kingdom, asphalt concrete mixes have always been prepared using the Marshall mix design method (Highway Design and Construction 1988). Dr.Kahn et al. (1986) stated that the "Marshall Method of mix design which was used on all the projects does not indicate the shear strength of the mix design and therefore does not eliminate the mixes which may prone to rutting". They have recommended the use of the Hveem stability test along with the Marshall requirements as criteria at the time of mix design to eliminate the mixes which may be prone to rutting. Because of the special traffic and climate conditions in the Kingdom, it seems likely that new design parameters, or even a new design method will have to be developed to cope with these conditions. Recently, a minimum Hveem stability value has been introduced in conjunction with the modified Marshall requirements for asphalt concrete mixes used in primer road construction. (Highway Design and Construction 1988).

e) Traffic, Climate and Soil Conditions

In the pavement design process, traffic, climate and soil (subgrade) data are all important parameters (factors). As shown in Table 4.5, both climate and its relation to material used and accuracy of investigation of soil type factors have major effects on the quality of asphalt concrete pavements (the EIN values for these factors are 87.10% and 83.87% respectively). Data related to traffic volume has an EIN value of 81.72%.

A survey done a few years ago indicated that the average gross and axle loads on Saudi Arabia and other Gulf state roads exceed the maximum allowable limits in many developed countries. Such traffic conditions make the transfer of pavement technology and experience from developed countries a tricky and often dangerous practice. (AL-Dhalaan M)

Maximum allowable load in the Kingdom has been set and enforced by MOC to control truck load a step which is essential for fulfilling the pavement design objectives.

Data related to soil characteristics (i.e. materials properties, bearing capacity,...etc.) influence pavement quality throughout the design of its structure. These data are essential for the design and preparation of a pavement's subgrade and structure layers. Within the Kingdom, extremely variable soil types (i.e. mountainous areas, sand dune areas and sabkha areas) exist along which a highway project may be constructed. Such variation in the soil type can represent various challenges to both pavement designers and contractors. In the pavement design process, the designer must have a fundamental knowledge of the way the materials are utilized and behave under traffic, environmental and subgrade conditions existing along the roadway. He should also have the ability to analyze the various forms of pavement distress, and their causes and to take them into consideration while designing the pavement structure.

Other specification related factors which have an a level of effect on the quality of asphalt concrete pavements are shown in Table 4.5. It has been concluded that the distress of asphalt concrete pavement in the Kingdom is due principally to the properties of the asphalt concrete materials (Khan et al. 1986, Sterling 1986, and Preventive Maintenance For Saudi Arabian Road System 1984). These problems must be solved through better material and mix design specifications. In order for a quality design and specification to be prepared, there must be an appreciation of expected performance levels and the key characteristics of a product which produces the desired performance. In other words, the relationship between materials quality and properties of mixtures should be clearly identified and kept in mined while designing an asphalt concrete mixtures.

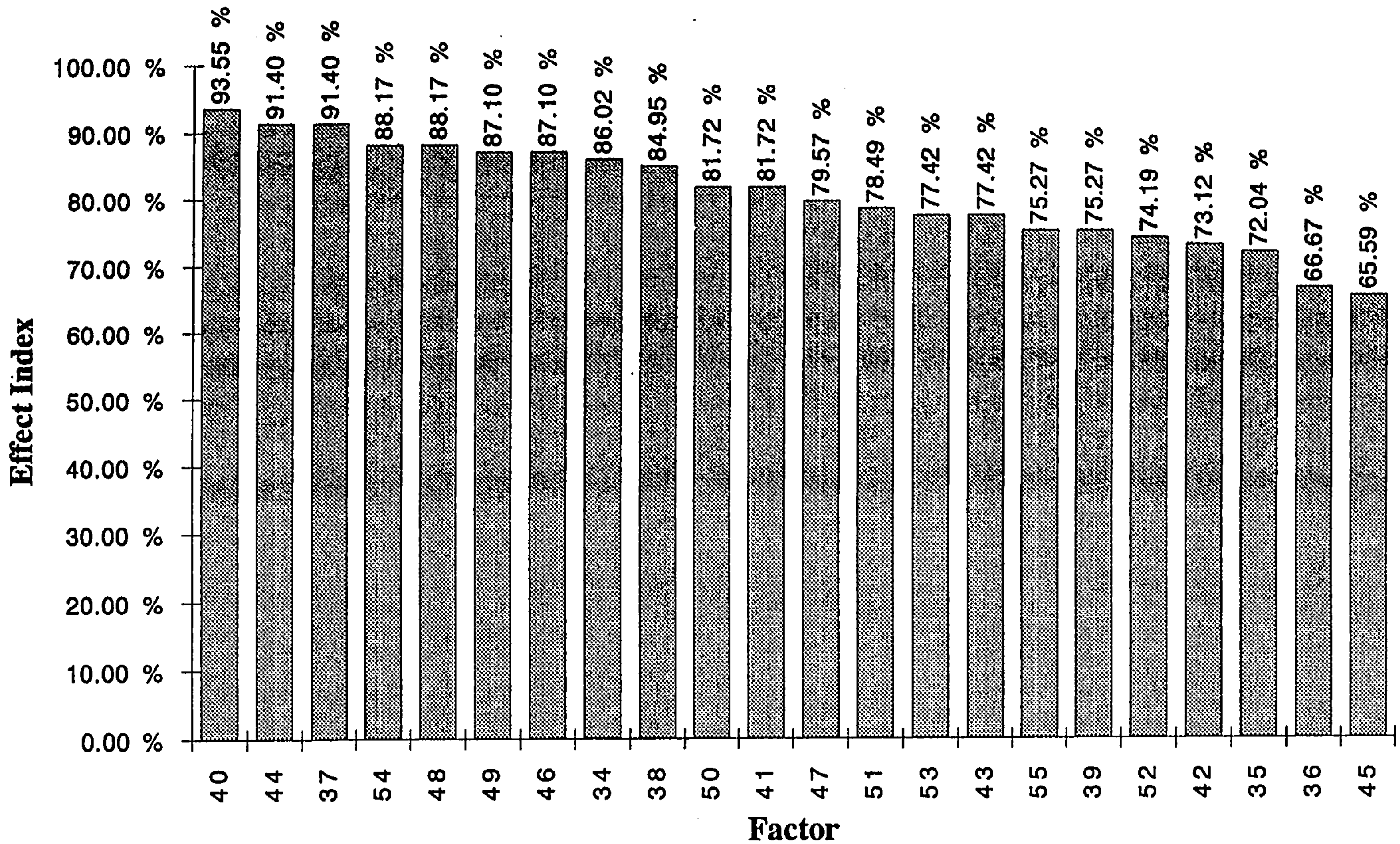
4.4.3- Construction Process Factors

If the selection of asphalt concrete pavement thickness is done properly and all materials selected are from acceptable resources, then the next phase which should done properly is the construction. During the construction phase, there are many factors which can alter the quality characteristics of the final product, from the source of material to mixing, placing and testing the finished asphaltic pavement. Control of aggregate gradation, amount of asphalt cement added to the aggregate, mixing temperature, and paving and compaction process are all critical factors for producing good asphalt concrete mixes. Table 4.6 shows the factors related to the construction process ranked according to their EIN values. Figure 4.3 shows these factors in histogram form.

Table 4.6 Construction Process Factors and their Degree of Effect on the Quality of Asphalt Concrete Pavement (from table 4.3)

DEGREE OF EFFECT	FACTOR #	FACTORS	EFFECT INDEX
MAJOR EFFECT	40	Aggregate quality (e.g. gradation, shape, type,...etc.).	93.55 %
"	44	Amount of filler materials in the mixture.	91.40 %
"	37	Availability of the specified material quality.	91.40 %
"	54	Compacting at wrong time.	88.17 %
"	48	Lack of experienced staff on contractor and owner team.	88.17 %
"	49	Condition of road bed soil.	87.10 %
"	46	The use of marginal material.	87.10 %
"	34	QC procedure performed by the owner team during construction.	86.02 %
"	38	Uniformity of material at source.	84.95 %
EFFECT	50	Uniformity of mixture placement and compaction operations.	81.72 %
"	41	Asphalt grade and quality.	81.72 %
"	47	Monitoring mixing operations.	79.57 %
"	51	Paver and roller mechanical condition and type.	78.49 %
"	53	Roller driver experience to observe mixture behavior.	77.42 %
"	43	Variation on asphalt content during mixture production.	77.42 %
"	55	Over-compaction.	75.27 %
"	39	Aggregate crushing process at material source.	75.27 %
"	52	Compacting pattern used to achieve the desired density.	74.19 %
"	42	Variation on aggregate gradation in stockpiles, mixing,...etc.	73.12 %
"	35	Contractor's QC for material at mixing plant stockpiles.	72.04 %
"	36	Owner's evaluation of the contractor's material source.	66.67 %
"	45	Continuous changing in mix design.	65.59 %

Figure 4.3 - Histogram - Construction Process Factors



a) Aggregate Quality, Availability and Crushing Process

Aggregate quality (gradation, shape, type,..etc.) which is used in asphalt mix production is one of the factors that have the highest EIN value (93.55%). The stability of an asphalt concrete mixture depends on the internal friction among the aggregate particles and cohesion from the bonding ability of asphalt (Webb 1986). The internal friction of an aggregate system depends highly on aggregate characteristics such as surface conditions, size, shape and hardness. A single stone (crushed) has high internal friction, whereas a single dune sand as a natural material has a very low internal friction (Pavement Rutting in the Kingdom of Saudi Arabia). It is therefore important to use well crushed angular aggregate from the sand fraction up to the maximum size of the aggregate. Dune sand should be totally excluded in asphalt concrete mix production specially for primary roads (DAR-ALhandasah 1986, Khan et al. 1986, and Pavement Rutting in the Kingdom of Saudi Arabia).

Table 4.6 shows that the availability of the specified material quality has the second highest EIN value (91.40%). In the Kingdom, there are three distinct regions, so far as the quality of aggregate for road construction is concerned. The Western and Northern regions have good quality aggregate with some areas of marginal aggregate. The Central region has an average quality aggregate, whereas the aggregate quality in the Eastern province area is generally marginal to average (Dubabe et al, and Highway Design and Construction

1988). Since, these regions encompasse different traffic, climate and subgrade conditions, variation in aggregate quality can result in difference in pavement performance within these regions, specially when standard aggregate specifications are used in the asphalt concrete pavement construction projects through the Kingdom. In addition, lack of good quality aggregate in some areas of the Kingdom, such as the Eastern Province, can result in higher construction costs, either due to the transportation of good aggregate quality from other regions or because of the rejection and rework of the construction work. Improvement in the aggregate production process in areas where aggregates are marginal seems to be essential to comply with specification requirements as well as to reduce the construction costs in these areas.

The aggregate crushing process has been shown to have an effect level (Table 4.6) with a lower EIN value (75.27%) than the other previous factors. Among the major factors in aggregate processing are the shape of the particles and the amount of natural sand after crushing. Dubabe et al, found that a "number of aggregate samples from various asphalt plants had excessive flat and elongated particles. Part of this is due to the nature of the aggregate but partly it is due to the type of crusher (secondary and territory) used". Since the shape of aggregate particles plays an important role in the resistance to permanent deformation, it is important that aggregate, including the sand, are angular crushed to give the most internal friction possible and thus higher mixture stability and resistance to permanent deformation under heavy loaded traffic. Proper aggregate selection methods and crushing processes are essential to achieve these desired aggregate characteristics. Currently, scalping of all aggregate is required by MOC specifications for primary roads to control the percentage of natural material. For marginal material (as it is the case in the Eastern Province) they have also recommended double crushing process to create durable particles (angular shape) (Khan et al 1986, Dubabe et al ,and Pavement Rutting in the Kingdom of Saudi Arabia).

Another aggregate related factor which has been shown (Table 4.6) to have a major effect on the quality of asphalt concrete pavements, is the use of marginal materials in mixture production (the EIN value is 87.10%). The properties of the materials as they interact independently or collectively in the pavement layer systems play a very important role in the performance and service life of the pavement. The use of lower quality materials will result in poor performance, specially under heavy loads and hot climate conditions. Khan et al. (1986) have found a large amount of the Kingdom's highways materials were very marginal so far as resistance to permanent deformation is concerned. Because of the heavy loads and hot climate conditions most of the pavements were rutted during their early life. Proper material selection and processing are essential to improve the materials quality, specially those which are marginal, in order to achieve higher pavement performance levels.

b) Amount of Filler Material

Table 4.6 shows that the amount of filler materials in the mixture has a major effect on the quality of asphalt concrete pavements. The EIN value for this factor is 91.40%, which is among the second highest factors. The amount and type of filler (all material passing No. 200 sieve) has an extreme influence on the mechanical properties of asphalt concrete mixtures (i.e. softening point of the bitumen-filler mortar, resistance to permanent deformation,...etc) (Hay and Kopac 1986. Pavement Rutting in the Kingdom of Saudi Arabia). The absence of the control on the softening point of the binder filler mortar as well as the range of filler materials that were used in the pavement construction, was considered as one of the main factors causing rutting in the Kingdom's highway pavements.(DAR-ALhandasah 1986, and Khan et al 1986).

Because of the hot climate and traffic conditions, most of the researches regarding rutting in the Kingdom's highway pavements, have recommended using filler from crushed aggregate and sand in a quantity between 1.3 - 1.5 times the bitumen content to increase the softening point of the bitumen-filler mortar to greater than 80 C (DAR-ALhandasah 1986, Khan et al 1986, and Pavement Rutting in the Kingdom of Saudi Arabia). As mentioned earlier, the MOC has currently adopted special requirements for filler content for primary roads. A filler to asphalt ratio of 1 to 1.5 is targeted at the optimum asphalt content to achieve a mortar softening point exceeding 75 C (Highway Design and Construction 1988).

c) Lack of Experienced staff

Table 4.6 shows that lack of experienced staff on contractor and owner team has the third highest EIN value (88.17%) among the construction process related factors. Because of the many activities involved in the asphalt concrete pavement construction process, such as material processing, stockpiling, mixing,...etc, the availability of knowledgeable and experienced engineers within both parties is essential to control the pavement production process to its desired quality. For instance, the owner needs well trained and experienced engineers and inspectors to visually verify that good materials are incorporated into the project and that good construction practices are followed to achieve a good end product. At the same time, the contractor requires experienced and qualified staff to manage the construction process and to maintain the desired quality.

All construction workers, skilled, semi-skilled and unskilled, in the Kingdom are expatriated from Far Eastern, and Middle Eastern countries and from Europe and the United States. Because of the unique environmental conditions in the Kingdom, which require special experience and knowledge in highway construction projects, many of the local construction and consultant firms have entered into a joint venture with foreign firms. To cut their running cost, some of these firms have employed young, inexperienced engineers to do their field supervision (AL Jarallah and Mohan 1986). Since the quality of a pavement is generally the product of materials utilized and construction processes followed, lack of an experienced staff can lead to inadequate material and process control resulting in low quality work. Currently, a personnel pre-qualification for any engineer to be involved during the construction phase has been adopted by the MOC. This is done to ensure that the contractor and consultant firms do have the required qualified staff and each engineer is qualified for the job he will be responsible for.

d) Quality Control Procedure Performed By the Owner Team

Table 4.6 shows that the quality control procedure performed by the owner team during construction has a major effect on the quality of the constructed pavement. The EIN value for this factor is 86.02%. The MOC inspection team is responsible for supervising and administering the project in accordance with approved contract documents. According to the MOC's Highway Construction Manual, Volume I, all inspections required are done by the engineer and his representative, where samples and testing required are performed by the contractor in the presence of an authorized representative of the engineer. Since controlling quality is primarily a sampling and testing problem, effective quality control program, based on the technical specification and desired level quality, is essential to achieve the desired quality. The inspector must be familiar with the material, construction process and sampling and testing procedures as well as the inherent variability associated with them in order to carry out the quality control plan effectively, so that the desired quality level is achieved.

e) Mixing Plant Operations

Mixing plant operations include aggregate stockpiling and handling, asphalt storage, mixing operations and transportation of the mix to the paving site. Proper plant operations are essential to produce asphalt concrete mixture that complies with the specification requirements. Table 4.6 shows some of the main plant operations factors with their EIN values and level of effect on the quality of asphalt concrete pavement. The following points discussed these factors and their effect on the mixture's quality.

1. Uniformity of material at source

Table 4.6 shows that the uniformity of material at source has a major effect on the quality of asphalt concrete pavement. The calculated EIN value for this is 84.95%. Aggregate at material source should be properly handled and stockpiled to ensure that a uniform material is being produced. The aggregate processor who intends to supply aggregate to pavement projects must control the variation of properties of his aggregate so that it is within the limits which will minimize the chances of rejection and costly penalties. Because the selection of the source is done prior to the mix design and the material is hauled to the plant site, adequate handling of the stockpiles is very important to ensure that there are materials present that meet the specifications and are essentially the same as those used in the development of the mix design. The contractor's quality control supervisor should maintain adequate test data on the material as its supplied to the plant to maintain uniformity

(Thay-Ming and Jenn-Fang 1988, and Webb 1986).

The other material which should be properly stored at source and plant site is asphalt cement. Asphalt cement grade and quality has been shown (Table 4.6) to have an effect on the pavement quality during the construction process. The EIN for this factor is 81.72%. In the Kingdom, asphalt cement grade, 60 - 70 penetration is used in asphalt concrete mixture production. This asphalt is produced by three refineries located in Riyadh, Jeddah and Ras Tanura. The materials sometime vary from one refinery to another due to the variation of the source (Highway Design and Construction, 1988). Because asphalt produced by these refineries are subjected to constant control during manufacture, it, as a general rule, complies with the specification. At the mixing plant, on the other hand, it might not comply with the requirement either because of storage at high temperature or accidental contamination in the delivery trucks or plant storage tank (Preventive Maintenance for Saudi Arabian Road System 1984). Therefore, the contractor's quality control supervisor should take all the necessary steps (i.e. sampling and testing) to ensure that asphalt cement at the plant storage tank complies with the specification. In addition to asphalt quality, asphalt quantities stored at the plant must be sufficient to allow uniform plant operation.

2. Mixing Operation

The mixing operation can have a dramatic effect on the consistency of the asphalt binder and the behavior of the finished mix during the laydown process. Table 4.6 shows that monitoring the mixing operation (i.e. aggregate composition, amount of asphalt cement added, mixing temperature and mixing time) has an effect on the final quality of the asphalt concrete mixture. The EIN value for this factor is 79.57%. It is very well known that aggregate composition, the amount of asphalt added to the aggregate and the temperature at the time of mixing all are very critical to producing good asphalt mixes. The control of the mixing time and temperature is an attempt to avoid the harmful possibility of creating too much fines (i.e. aggregate degradation) and reducing the aging of the asphalt (oxidation) so that a uniformly coated and homogeneous mixture is produced (Thay-Ming, and Jenn-Fany 1988). The mixture produced should be sampled and tested for asphalt content, aggregate gradation, Marshall properties, ...etc., so that any evidence of assignable causes can be detected before rejections occurs.

3. Variation During Mixing

Uncontrolled variation in materials and process can alter the quality characteristics of the final mixture. Controlling variability in the pavement construction process (i.e. material, mixing,...etc.) is essential to managing the construction process so that the desired mixture quality is achieved.

Table 4.6 shows that variation in the asphalt content during mixture production has an effect on the mixture quality. The EIN value for this factor is 77.42%. The proportion of asphalt content in the mixture is critical and must be accurately determined and precisely controlled during the mixing operation. The proper asphalt content is critical in obtaining the desired void content in the compacted mixture, and affects durability, flexibility, stability and susceptibility to moisture damage. Variation in the asphalt content can result in either a dry mix which might lead to premature raveling and cracking, or in rich mixes which might be subjected to flushing and loss of stability under traffic. Therefore, it is necessary to control the asphalt content within very a close tolerance.(Hay and Kopac 1986).

Variation in aggregate gradation has also been shown to have an effect on the mixture quality but its EIN value (73.12%) is lower than that for variation in asphalt content (77.42%). The reason for this lower value may be due to the fact that aggregate gradation during the mixture operation is probably the most easily controlled properly (Kopac 1986, and Thay-Ming and Jenn-Fang 1988). While any one of many gradations can be used to produce a satisfactory mix design and production, it is necessary to maintain a given gradation once the mix design is selected. Similar to asphalt content, change in gradation will result in problems of achieving the proper void content in the finished pavement. Allowing the gradation to fluctuate beyond the controlled limit during mix production can create tender mixes that are impossible to compact properly. Because the VMA is directly related to the aggregate gradation, variation in the gradation may result in lower VMA value. As mentioned earlier, low VMA value may indicate that either the asphalt content or air void content may deviate from the tolerance limits, affecting the desired mixture's properties (DAR-ALhandasah 1986, Khan et al. 1986 and Preventive Maintenance for Saudi Arabian Road System 1984).

f) Placement and Compaction Process

If placement and compaction of the mix is not done properly all of the efforts in selecting and testing materials and designing and producing the hot mix and its cost are largerly wasted. The placement and compaction procedure, equipment and the precautions required are very well defined in the General Specifications. The following points will discuss some of the factors during the placement and compaction process which have great effect on the finished asphalt concrete pavement.

1. Surface Condition

The surface condition of the pavement layers (i.e. subgrade, aggregate subbase and base) prior to placing asphalt concrete mixture has been shown to have a major effect on the quality of asphalt concrete pavements. As shown in Table 4.6, the EIN value for this factor is 87.10%. The riding quality of the asphalt concrete pavement depends largely on proper construction and preparation of the structural layers beneath the asphalt concrete layers. Proper compaction of these layers is very important for the performance of the asphalt layers. When the subgrade, aggregate subbase and base are not sufficiently compacted, additional consolidation may occur under traffic resulting in settlement and possible failure in the asphalt concrete layers. In the Kingdom, due to the selection of materials for subgrade, aggregate subbase and base and the required degree of compaction, no deflection has happened in these courses even with roads with heavy rutting conditions (Pavement Rutting in the Kingdom of Saudi Arabia, and Sterling 1986).

2. Uniformity of Mixture Placement and Compaction Process.

This factor, as shown in table 4.1, has an effect on the pavement quality (the EIN value is 81.72%). During the placement process several things can happen affecting the quality of the finished pavement such as segregation during mix transportation, variation in mix temperature, insufficient flow of material to the paver, type and number of paver and weather conditions. Therefore the engineer and his inspectors with the contractor's representatives should carefully plan the entire placement and compaction operation. The plan should include the sequence of the operation, the amount and type of hauling equipment required, the type and number of paver and rollers needed, equipment adjustments and any precautions required to achieve the specified finished pavement. A close cooperation between the plant and paving site is essential in securing a satisfactory and uniform flow of the mixture within its proper temperature so that a smooth mat surface, and a uniform mat thickness and density is achieved.

3. Compaction Process

Compaction with rolling equipment is the final stage of the pavement construction process and it is the most important factor in ensuring satisfactory pavement performance during its service life. Lack of adequate compaction during construction will result in low pavement density. This low density generally results in long term deterioration such as raveling and cracking from traffic. If the specified density is not obtained during construction, subsequent traffic will further consolidate the pavement. This consolidation occurs principally in the wheel path and appears as a channel in the pavement surface forming rutting. Therefore it is very important to achieve the specified density at the time of construction.

During the compaction process, several factors can affect the ability to achieve the specified pavement density. These include mixture temperature, rolling equipment type and conditions, compaction pattern rollers , driver experience and weather condition. Table 4.6 shows these factors with their calculated EIN value. The EIN value of these factors range from 88.71% to 74.19%, which indicate the level of effect that these factors can have on the final quality of the pavement.

Table 4.6 shows that compaction at the wrong time has the third highest EIN value (88.17%) among the construction process related factors. The best time to compact an asphalt mixture is when its resistance to compaction is the least while at the same time it is capable of supporting the roller without excessive shoving and displacement. This time is influenced by the mixture production temperature, the mixture's temperature during placement, mat thickness, air temperature and wind velocity. Mix delivered to the site must be within the proper temperature. If the mix reaches the paving site at a temperature below which it can be compacted, it should be rejected. The reason for this is that compaction can only occur while the asphalt binder is fluid enough to act as a lubricant. When it cools too much, further compaction is extremely difficult to achieve.

Another important activity to be done while compacting asphalt concrete mixture is monitoring the process while it is in progress. A nuclear gage density reading can be a very effective approach of measuring the pavement density during the compaction process. With the nuclear gage approach immediate data is available to the field personnel so that they have the opportunity to correct or modify the compaction process without any delay to achieve the desired density.

g) Contractor Quality Control

Table 4.6 shows that the contractor's quality control of material at the mixing plant can have an effect on the quality of asphalt concrete pavements. The EIN value for this factor is 72.04%. Since the contractor is the party who constructs the project, he is the sole party to the contract who has direct control of the quality of the constructed project (Bayless 1986 and Powell 1986). The contractor is required to furnish all labor, equipment and materials necessary for constructing the project to its specified quality. Therefore, beyond causing the work to be performed, materials used and construction process followed must be controlled to ensure that the end product is in compliance with the specification requirements.

The contractor's quality control should represent actual control of the material and process to steer the quality of the pavement. Effective contractor's quality control will enable the contractor to check (a) the quality and uniformity of the material prior to and after mixing, (b) the adequacy of his construction procedures, and (c) the performance of his labor and equipment.

4.4.4. Acceptance (Handing Over Procedure) Factors

When the project is ready for handing over, either partially or completely, a preliminary handing over committee is formed. The committee has the responsibility for checking all the items of the work to see whether the work is executed in accordance with the specified requirement of the project or not. In case some of the items show deviation from the specifications, they cannot be accepted until they are reworked to satisfy the requirements. In case the rework is not possible or would affect other items considerably, then the safety of the pavement structure, and its service quality should be studied. If it is found unsafe, some remedial measure or rejection should be proposed. If in the opinion of the committee, the pavement structure is found safe and useable, then the work can be accepted with appropriate deduction from the cost of the work. The deduction represents the amount of effort that the contractor has not spent in constructing the work to its specified requirement. Final Acceptance of the work is reserved for the Ministry at the Final Handover which takes place after a 360 day period of maintenance following the date the work is determined to be 100% complete. If any part of the pavement becomes defective during the maintenance period, the contractor is required to fix or replace it.

Table 4.7 shows the acceptance related factors ranked according to their calculated EIN values. Figure 4.4 shows the histogram for these factors. The EIN values indicate that acceptance related factors have a level of effect on the quality of the pavement.

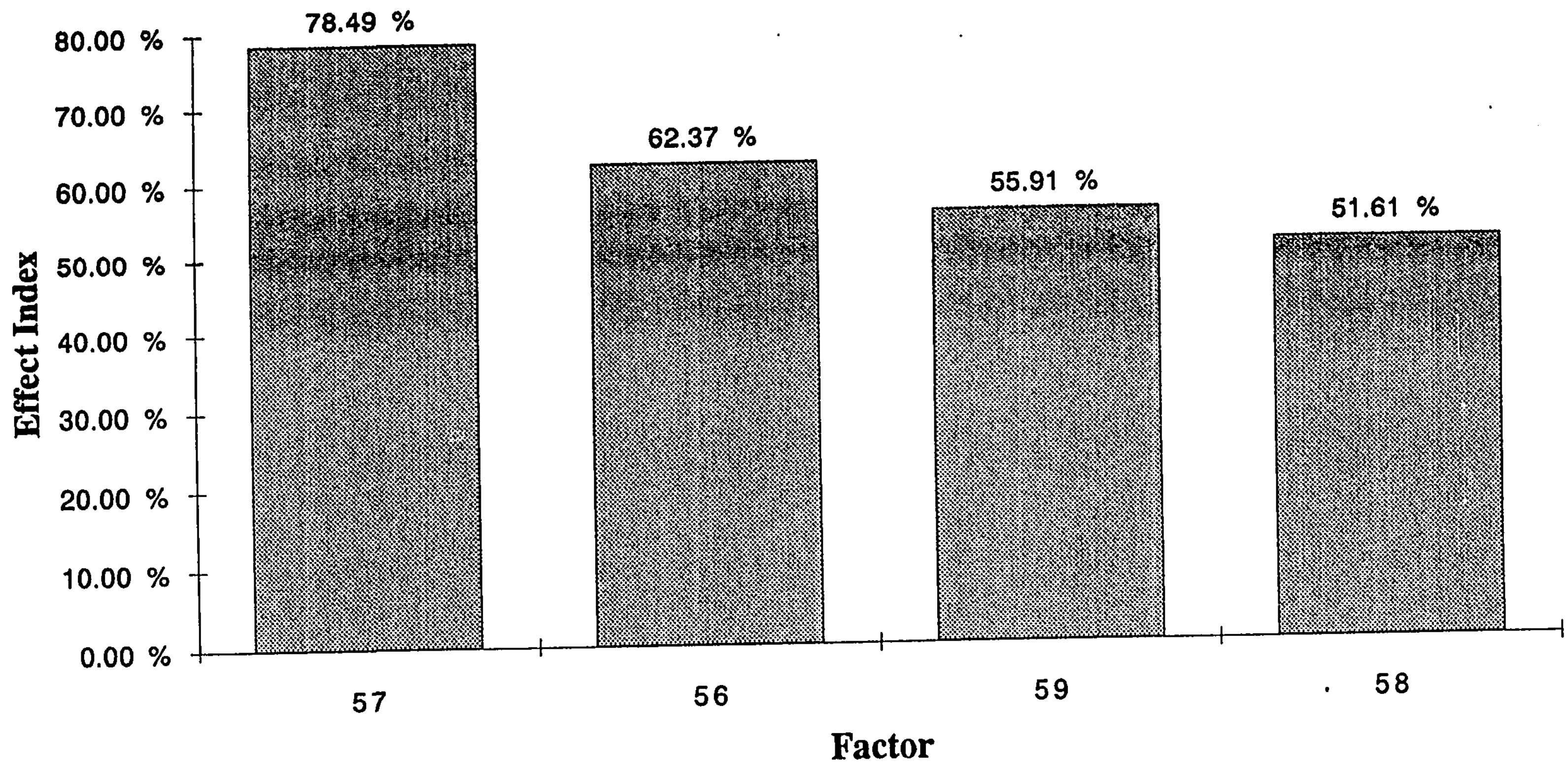
a) Qualification of the People Performing Acceptance Procedure

Qualification of the people performing the acceptance procedure has been shown to have an influence on the quality of asphalt concrete pavements. The EIN value for this factor is 78.49% which represents the highest EIN value among the acceptance related factors (see Table 4.7). The preliminary handing over committee responsible for checking the pavement's compliance with the specification consists of the representatives of the MOC (including material engineer, material inspector, structural engineer,...etc.), the

Table 4.7 Acceptance (Handing over procedure) Factors and their Degree of Effect on the Quality of Asphalt Concrete Pavement (from table 4.3)

DEGREE OF EFFECT	FACTOR #	FACTORS	EFFECT INDEX
EFFECT	57	Qualifiction of the people performing acceptance procedures.	78.49 %
"	56	Evaluation practices used for product acceptance.	62.37 %
"	59	Fairness of the method adopted by the MOC for deduction.	55.91 %
"	58	Amount of payment deduction for non-compliance product.	51.61 %

Figure 4.4 - Histogram - Acceptance (Handing Over) Factors



the representative of the consultant (the same engineers who supervised the work or have some knowledge about the project) and the representative of the contractor. In other words the committee will consist of the representatives of all the concerned parties who are involved in the execution of the project. Their qualification and experience is of great importance since they will determine whether the project is in compliance with or has deviated from the specifications in which rejection or acceptance with deduction decisions are made. The inclusion of representatives of all parties will ensure fair treatment of the acceptance requirements for all parties.

b) Evaluation Practices Used for Asphalt Pavement Acceptance.

Table 4.7 shows that the evaluation practice used for product acceptance can have an effect on the quality of asphalt concrete pavements. The EIN value for this factor is 62.37%. The low EIN value may be due to the difficulty in quantifying the effect of the acceptance procedure on the quality of the pavement. However, the clarity of the acceptance procedure (i.e. sampling procedure, test method, quality characteristics to be tested and the test data evaluation process) and how they are carried out are extremely important in determining the product's quality and its degree of compliance with the specifications. If the specifications do not clearly define the acceptance procedure or are not properly carried out, an inaccurate estimation of the quality may result. This can lead to wrong acceptance decisions (i.e. acceptance of unsatisfactory work or rejection satisfactory work).

For project evaluation the handing over committee, after studying the report prepared by the project's consultant, decides on the number of test locations and the types of tests to be carried out so as to obtain a dependable representative condition of the project. A layout is prepared by the committee showing the locations of the test samples and pavement layers to be tested.

Four types of sample tests (pits) are made for an asphalt concrete pavement evaluation. These are a) a big test pit for deep testing (to analyze bituminous wearing and base course mixes, aggregate base course, granular subbase, subgrade, and any accessible layer of embankment); b) a medium test pit for testing up to the subgrade layer; c)cores for asphalt layers (to determine thickness and compaction determination of asphalt layers); and d) a test pit for testing shoulders. Each test pit represents a designated portion or section of the roadway. The minimum test pits for handing over procedures are shown in Table 4.8. For each test pit, the committee tests the hot mixed bituminous concrete of the pavement for asphalt content, aggregate gradation, mixture density and compaction. The committee is also required to visit the project for a visual field inspection to observe apparent defects like bleeding, reveling, and rutting on the road surface as well as to access the riding quality of the road.

Table 4.8- Minimum test pits required for MOC handing over procedure.*

Roadway Length	Number of Pit		
	Big Pits	Medium Pits	Cores
0 - 5 Km	1	2	8
5 - 20 Km	2	3	12
20 - 50 Km	3	4	16
50 - 100 Km	4	5	20
more than 100 Km	one per 25 Km	between each two big pits one or more medium pits and between each two medium pits two or more cores.	

* (MOC Handing Over Manual)

After performing the required handing over tests,the committee meets to discuss the test results, apparent defects, if any, in the project any necessary, remedial measures. For an asphalt concrete pavement, each section is evaluated in term of the following quality characteristics: (a) asphalt content as per Marshall design; (b) quality of asphalt cement used, 60 - 70 or any other type; (c) quality of asphalt mix (percent air voids, voids in Mineral aggregate, stability, ...etc.); (d)quality of aggregate; (e) grading of aggregate; (f) compaction; (g) layer thickness; and (h) riding quality. The committee views the results of the test of each characteristic alone.

The process of evaluating each quality characteristic is done by comparing test results with the specified target and tolerance limits. When the quality characteristic tested is within the specified tolerance, the committee accepts it. When the quality characteristic deviates from the tolerance, but the deviation, based on the committee's opinion is minor and will not effect the utility and durability of the pavement, the quality characteristic can be accepted with an appropriate deduction from the cost of the tested quality characteristic. In case of major deficiency and the tested section(s) are not meeting the specification, the matter, along with the report and findings of the committee, shall be referred to MOC experts for final decision and the process of handing over shall be completed for acceptance works only. When the repair of deficient works are to be undertaken by the contractor the handing over process can be delayed for a reasonable period. If the contractor wishes not to complete the repairs and these uncompleted works do not affect the utility of the pavement, the committee may with the agreement of the contractor deduct the money for the repairs and finalize the report and the process of handing over.

c) Payment Deduction

Payment deduction for non-compliance materials or work offers the solution when the tested works are not sufficiently bad to warrant removal and replacement. Table 4.7 shows that the fairness of the method adopted by the MOC for deduction and the amount of deduction for non-compliance product have an effect on the quality of asphalt concrete pavements. The EIN values of these two factors are 55.91% and 51.50% respectively.

The MOC has prepared a deduction procedure to be used by any committee responsible for project handing over so that variations in the amount of deduction from one committee to another is eliminated. For asphalt concrete layer evaluation, each roadway section is presented by samples. The committee will make deductions for the section represented by the samples not complying with the specification. As mentioned earlier, several quality characteristics may be used for an asphalt concrete layer evaluation. Each quality characteristic will have an equal value to the other characteristics of the asphalt concrete being evaluated. The MOC procedure for deductions for various asphalt concrete quality characteristics is shown in Appendix C along with an example of deduction calculation for one of the MOC projects (Abu-Hadriyh - Dammam Express way No. 1, section "C").

4.5 - Rank Correlation

Four classes of contractors were surveyed. These were grades one to four. grade 1 contractors represent the largest class in terms of capability (i.e. equipment, labor, and finances) and amount and size of work performed, whereas grade 4 contractors represent the lowest contractors who usually perform a portion of a project or maintenance work. The relationship between contractor grades and the Effect Index were determined (i.e. the agreement between any two contractor's grades on the factors Effect Index ranking).

In order to achieve the above objective, Effect Index EIN values are calculated for each contractor grade. Appendix D shows the factor tables ranked according to the EIN values for contractor grades 1, 2, 3, and 4. To measure the degree of the relationship, the factors in each EIN table are ranked out of the number of factors surveyed (i.e. 59). When two or more factors have the same rank, we add them and then divide the results by the number of factors having the same rank. Table 9, 10, 11, and 12, in Appendix D, show the ranked factors for contractor grade 1, 2, 3, and 4 respectively. Table 13 shows the ranked factors for all contractor grades.

The method used to find and compare how well any two contractor grades agree on the factor EIN rank is the

Spearman Rank Correlation. The formula used to calculate the Spearman rank correlation coefficient (r) for any two grades of contractors is:

$$rij = 1 - \frac{6 \quad * \sum \quad d2}{N \ (\ N2 \ - \ 1 \ )} \qquad (4.1)$$

Where :

rij = Spearman Rank Correlation (agreement) between Grade i and grade j contractors on the Effect Index of factors affecting asphalt concrete quality.

N = Number of factors = 59

d = Difference between ranks on one grade and on another grades of contractors. (Table 14 to 19, Appendix D)

Table 4.10 shows the Spearman Rank Correlation coefficient values. The detailed calculation procedure can be found in Appendix D.

The correlation coefficient (Table 4.9)shows the existing agreement and the degree of this agreement between each pair of contractor grades on the factors's EIN. The positive correlation coefficients indicate that all of the contractor's grades are aware of the effect that the surveyed factors can have on the quality of asphalt concrete pavements. As shown in Table 4.9, the highest agreement between any two contractor grades is the one between

Table 4.9- Spearman Rank Correlation Coefficient Values.

Spearman Correlation Coefficient
r_{12} = 0.590
r_{13} = 0.585
r_{14} = 0.582
r_{23} = 0.735
r_{24} = 0.422
r_{34} = 0.518

agreement between any two contractor's grade is the one between contractor's grade 2 and 3 ($r23$ = 0.735). On the other hand, the lowest agreement is between between contractor grades 2 and 4 ($r24$ = 0.422). The high Spearman rank correlation coefficient between contractor grades 2 and 3 could be due to the number of asphalt concrete roads they have been constructing in the Kingdom.

4.6 - Hypothesis testing

The hypothesis that all contractor grades have the same factor's EIN is tested. The test (the agreement between all contractor grades) is done for the difference between all means for each factor. The analysis of Variance (ANOVA) procedure is used. The ANOVA is a technique for comparing the means of any number of populations (i.e. contractor grades). Since four contractor grades are involved in this study, ANOVA is used for testing the equality of the four means (agreement between all contractor grades) for each factor. The hypothesis (agreement) will be tested by comparing the calculated value of F with the critical F value at 5% significant level (α = 0.05).

The hypothesis test for the difference between all means for factor No.i is :

$$\mathbf{Ho : \bar{X}1 = \bar{X}2 = \bar{X}3 = \bar{X}4}$$

Versus

Ha : At least two means differ.

or

Ho : All contractor's grades have the same factor's EIN.

versus

Ha : At least two contractor's grades among the four grades do not have the same factor's EIN.

A computer SAS program (SAS Analysis of Variance Procedure) was used at KFUPM to do the test for each factor . A sample of the SAS ANOVA procedure computer output is shown in Appendix D for factor No.1.

With the condition that the variance for $\overline{X}_1$, $\overline{X}_2$, $\overline{X}_3$ and $\overline{X}_4$ are equal the decision rule for accepting or rejecting the null hypothesis is:

Fstat < F	then accept the H_o
Fstat > F	then reject the H_o

The critical F value corresponding to $\alpha = 0.05$ and $V1 = K-1$, and $V2 = n-k$ degree of freedoms is given in Table Percentage Point of the F Distribution. The critical F value at $\alpha = 0.05$ and $V1 = 4-1 =3$, and $V2 = 31-4 = 27$ is found to

Table 4.10- ANOVA Result Fo Hypothesis Tes For The Differeence Between All Means.

FACTOR NO	MEAN	STD	SST	SSE	MST= SST/3	MSE= SSE/27	F= MST/MSE	F 0.05 TABLE	DECISION RULE
1	2.55	0.72	2.54	13.14	0.85	0.49	1.74	2.96	ACCEPT
2	2.55	0.62	0.28	11.40	0.09	0.42	0.22	2.96	ACCEPT
3	2.48	0.72	0.60	15.14	0.20	0.56	0.36	2.96	ACCEPT
4	1.94	0.96	3.22	24.65	1.07	0.91	1.18	2.96	ACCEPT
5	2.19	0.75	1.28	15.56	0.43	0.58	0.74	2.96	ACCEPT
6	1.97	1.08	5.15	29.80	1.72	1.10	1.56	2.96	ACCEPT
7	2.48	0.51	0.92	6.82	0.31	0.25	1.21	2.96	ACCEPT
8	2.23	0.84	0.55	20.37	0.18	0.75	0.24	2.96	ACCEPT
9	2.48	0.72	3.00	12.74	1.00	0.47	2.12	2.96	ACCEPT
10	1.16	0.69	1.05	13.14	0.35	0.49	0.72	2.96	ACCEPT
11	2.10	0.75	3.09	13.62	1.03	0.50	2.04	2.96	ACCEPT
12	1.94	0.81	3.78	16.09	1.26	0.60	2.11	2.96	ACCEPT
13	2.16	0.73	2.93	13.27	0.98	0.49	1.99	2.96	ACCEPT
14	2.81	0.48	0.48	6.35	0.16	0.24	0.68	2.96	ACCEPT
15	2.68	0.65	0.30	12.47	0.10	0.46	0.22	2.96	ACCEPT
16	1.87	0.99	6.97	22.52	2.32	0.83	2.78	2.96	ACCEPT
17	2.52	0.51	1.27	6.47	0.42	0.24	1.77	2.96	ACCEPT
18	2.45	0.68	1.03	12.65	0.34	0.47	0.73	2.96	ACCEPT
19	2.61	0.72	1.64	13.72	0.55	0.51	1.08	2.96	ACCEPT
20	2.13	0.92	1.86	23.60	0.62	0.87	0.71	2.96	ACCEPT
21	2.81	0.40	0.42	4.42	0.14	0.16	0.85	2.96	ACCEPT
22	2.52	0.68	0.68	13.07	0.23	0.48	0.46	2.96	ACCEPT
23	2.61	0.67	0.07	13.29	0.02	0.49	0.05	2.96	ACCEPT
24	2.58	0.62	0.59	10.96	0.20	0.41	0.49	2.96	ACCEPT
25	2.10	0.98	2.50	26.21	0.83	0.97	0.86	2.96	ACCEPT
26	1.65	0.75	2.18	14.92	0.73	0.55	1.32	2.96	ACCEPT
27	1.87	0.81	1.37	18.12	0.46	0.67	0.68	2.96	ACCEPT
28	2.68	0.54	0.26	8.51	0.09	0.32	0.27	2.96	ACCEPT
29	2.35	0.84	4.76	16.34	1.59	0.61	2.62	2.96	ACCEPT
30	2.23	0.80	1.17	18.25	0.39	0.68	0.58	2.96	ACCEPT

Table 4.10- Continue

FACTOR NO	MEAN	STD	SST	SSE	MST= SST/3	MSE= SSE/27	F= MST/MSE	F 0.05 TABLE	DECISION RULE
31	2.32	0.65	1.86	10.92	0.62	0.40	1.53	2.96	ACCEPT
32	2.16	0.82	1.59	18.61	0.53	0.69	0.77	2.96	ACCEPT
33	2.58	0.85	0.81	20.74	0.27	0.77	0.35	2.96	ACCEPT
34	2.58	0.67	0.48	13.07	0.16	0.48	0.33	2.96	ACCEPT
35	2.16	0.82	1.06	19.14	0.35	0.71	0.50	2.96	ACCEPT
36	2.00	0.93	5.11	20.89	1.70	0.77	2.20	2.96	ACCEPT
37	2.74	0.51	0.11	7.82	0.04	0.29	0.13	2.96	ACCEPT
38	2.55	0.57	0.14	9.54	0.05	0.35	0.13	2.96	ACCEPT
39	2.26	1.00	0.38	29.56	0.13	1.09	0.12	2.96	ACCEPT
40	2.81	0.48	0.59	6.25	0.20	0.23	0.85	2.96	ACCEPT
41	2.45	0.72	0.76	14.92	0.25	0.55	0.46	2.96	ACCEPT
42	2.19	0.83	1.08	19.76	0.36	0.73	0.49	2.96	ACCEPT
43	2.32	0.83	1.72	19.05	0.57	0.71	0.81	2.96	ACCEPT
44	2.74	0.63	1.60	10.34	0.53	0.38	1.39	2.96	ACCEPT
45	1.97	1.11	7.16	29.81	2.39	1.10	2.16	2.96	ACCEPT
46	2.61	0.50	0.47	6.89	0.16	0.26	0.61	2.96	ACCEPT
47	2.39	0.67	1.55	11.81	0.52	0.44	1.18	2.96	ACCEPT
48	2.65	0.55	1.34	7.76	0.45	0.29	1.55	2.96	ACCEPT
49	2.61	0.50	0.48	6.87	0.16	0.25	0.63	2.96	ACCEPT
50	2.45	0.68	0.76	12.92	0.25	0.48	0.53	2.96	ACCEPT
51	2.35	0.61	1.01	10.09	0.34	0.37	0.90	2.96	ACCEPT
52	2.23	0.72	0.81	14.61	0.27	0.54	0.50	2.96	ACCEPT
53	2.32	0.75	0.30	16.47	0.10	0.61	0.17	2.96	ACCEPT
54	2.65	0.61	1.28	9.82	0.43	0.36	1.17	2.96	ACCEPT
55	2.26	0.77	0.11	17.82	0.04	0.66	0.06	2.96	ACCEPT
56	1.87	0.81	0.33	19.16	0.11	0.71	0.15	2.96	ACCEPT
57	2.35	0.84	0.62	20.47	0.21	0.76	0.27	2.96	ACCEPT
58	1.55	1.06	0.94	32.74	0.31	1.21	0.26	2.96	ACCEPT
59	1.68	0.98	0.97	27.81	0.32	1.03	0.31	2.96	ACCEPT

be 2.96. Table 4.10 shows the ANOVA calculation values (mean, standard deviation, SST, SSE, MST, MSE and Fstatistic) for each factor. The critical value of F and the decision rule for accepting or rejecting the null hypothesis are also shown in the table. The formulas used to calculate these values are shown in Appendix D.

Since the calculated value of F for each factor is less than the critical value of F, the null hypothesis is accepted for all factors, and it is concluded that all contractor grades agree on the factor's EIN affecting the quality of asphalt concrete pavements.

4.7- Factor Occurrence in the Kingdom of Saudi Arabia

In addition to those factors which have a major effect on the quality of asphalt concrete pavement, factors which are most frequently occurred in highway pavement construction in the Kingdom were also determined. The frequency of contractors who answered "Yes" (i.e. that this factor does occur in the Kingdom) gives an important indication for those factors which have a major effect on the quality and do occur in the Kingdom. This results in a recommendation to study those factors in more detail in future researches. Unfortunately a few respondents had answered the part related to factors occurrence, most of the respondents did not answer that part of the questionnaire. Consequently the observed data cannot be taken as concrete results.

Table 4.11 shows the frequencies of the contractors who indicated the occurrence of the factors affecting the quality of asphalt pavement in the Kingdom. Figure 4.5 shows the histogram of these factors. Some of these factors have been already discussed in detail in part 4.4 (the Effect Index). The following points discuss the main occurrence factors.

4.7.1- Managerial Factors:

a) Selection of the lowest bidder to construct the project:

This factor has a level of effect on the pavement's quality (Table 4.4). As shown in Table 4.11, eleven (11) contractors indicated that this is a factor which has occurred in the Kingdom. The procurement law for public projects states that the project is awarded to the lowest qualified bidder. Awording the contract solely based on the bid amount can result in selecting a contractor who is not qualified enough in constructing the project to its specified quality.

b) Clarity of responsibilities and authorities:

As shown in Table 4.4, this factor has a major effect on the pavement's quality. In Table 4.11, eight (8) contractors indicated that this is a factor which has occurred in the Kingdom. Quality is the achievement of a team effort. Because of the numerous personal interactions during the construction phase, adverse relationships can evolve which may jeopardize the quality of the finished work.

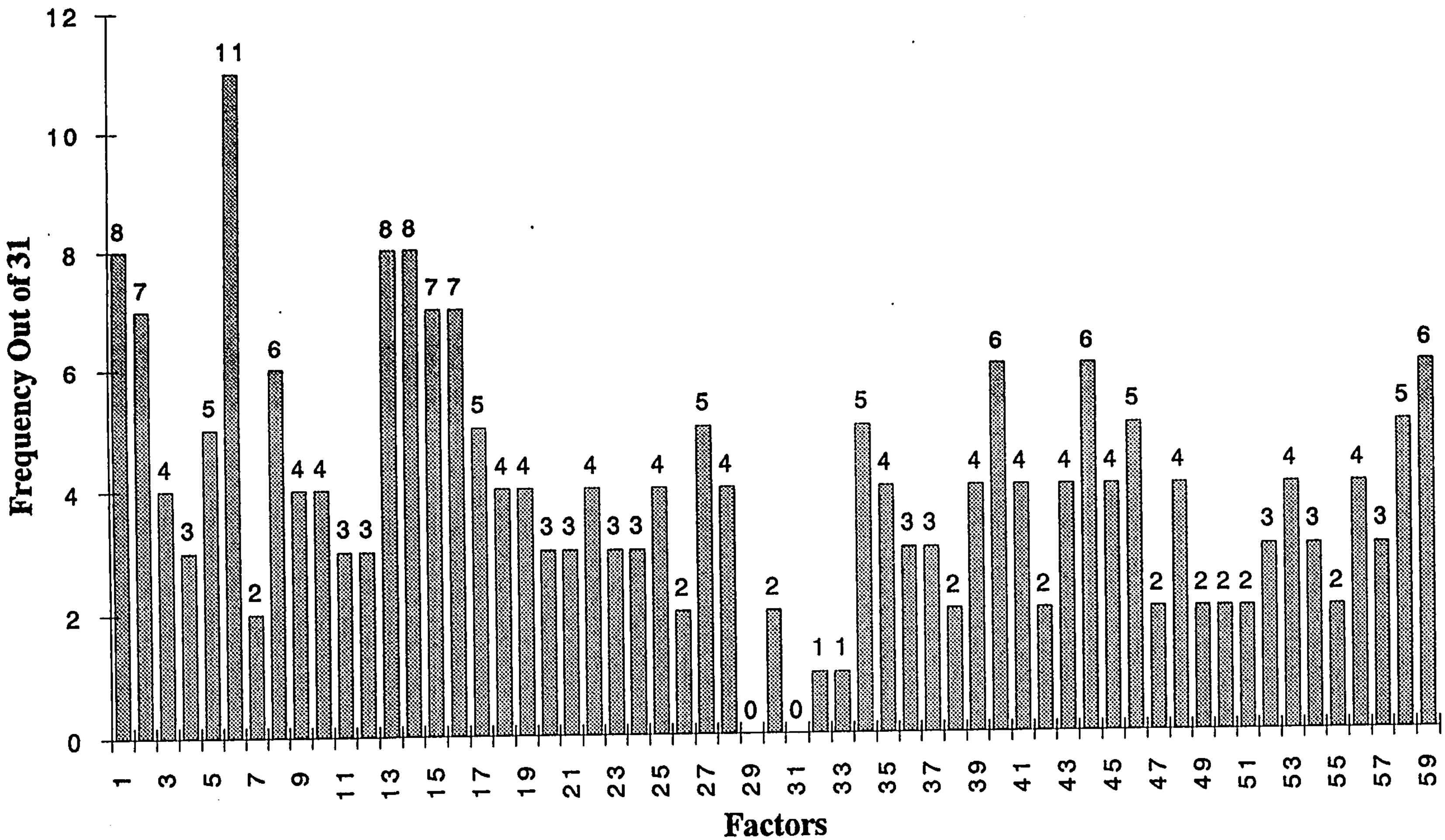
Table 4.11 - Factor's Occurance Frequency In The Kingdom Of Saudi Arabia

	FACTOR	CONTRACTORS ANSWERED YES	PERCENT*
	A - MANAGERIAL		
1	Clarity of responsibilites and authority.	8	26%
2	Qualification of the owner's inspection team.	7	23%
3	Owners team familiarity with the construction process.	4	13%
4	Assignment of QC responsibility to the consultant.	3	10%
5	Qualification of contractors during bidding process.	5	16%
6	Selection of the lowest bidder to construct the project.	11	35%
7	Contractor's previous experience.	2	6%
8	Contractor's financial status during construction.	6	19%
9	Contractor's labor and equipment capability.	4	13%
10	Amount of work sub-contracted.	4	13%
11	Cost escalation of material, labor ...etc.	3	10%
12	Financial incentives to produce higher quality level.	3	10%
13	Delay in contractor progress payment.	8	26%
	B - DESIGN AND SPECIFICATION		
14	Pavement not designed to the regional conditions.	8	26%
15	Design errors from inaccurate assumptions, data...etc.	7	23%
16	Insufficient owner involvment during design phase.	7	23%
17	Accuracy of investigation on soil type.	5	16%
18	Accuracy of data related to traffic volume,...etc.	4	13%
19	Climate and its relation to materials used.	4	13%
20	The use of full depth asphalt concrete cross-section.	3	10%
21	Consistency of specification interpretation of aggregate quality.	3	10%
22	Consistency of specification interpretation of asphalt quality & content.	4	13%
23	Consistency of specification interpretation of mixture composition.	3	10%
24	Consistency of specification interpretation of compaction level.	3	10%
25	Level of technical details required to specify the desired product quality.	4	13%
26	Over-specification of materials and equipment,...etc.	2	6%
27	Limitation on material source selection, equipment type,...etc,	5	16%
28	Mix design does not consider the local conditions.	4	13%
29	Mix design method used locally.	0	0%
30	The use of dense graded job mix formula for mixture production.	2	6%
31	The use of open graded job mix formula for mixture production.	0	0%

Tab!e 4.11 - Continue

	FACTOR	CONTRACTORS ANSWERED YES	PERCENT*
32	Wide job mix formula tolerances.	1	3%
33	Asphalt mixture properties (e.g. stability, durabilty,...ect.).	1	3%
	C - CONSTRUCTION PROCESS		
34	QC proceduer performed by the owner team during construction .	5	16%
35	Contractor's QC for material at mixing plant stockpiles.	4	13%
36	Owner's evaluation of the contractor's material source.	3	10%
37	Availability of the specified material quality (e.g. aggregate asphalt).	3	10%
38	Uniformity of material at source (ie. Aggregate gradation - asphalt grade).	2	6%
39	Aggregate crushing process at material source.	4	13%
40	Aggregate quality (e.g. gradation, shape, type,...etc.).	6	19%
41	Asphalt grade and quality.	4	13%
42	Variation on aggregate gradation in stockpiles, mixing,...etc.	2	6%
43	Variation on asphalt content during mixture production.	4	13%
44	Amount of filler materials in the mixture.	6	19%
45	Continuous changing in mix design.	4	13%
46	The use of marginal material.	5	16%
47	Monitoring mixing operations.	2	6%
48	Lack of experienced staff on contractor and owner team.	4	13%
49	Condition of road bed soil.	2	6%
50	Uniformity of mixture placement and compaction operations.	2	6%
51	Paver and roller mechanical condition and type.	2	6%
52	Compacting pattern used to achieve the desired pavement density.	3	10%
53	Roller driver experience to observe mixture behavior under roller.	4	13%
54	Compacting at wrong time.	3	10%
55	Over-compaction.	2	6%
	D _ ACCEPTANCE (HANDING OVER PROCEDURE)		
56	Evaluation practices used for product acceptance.	4	13%
57	Qualifiction of the people performing acceptance procedures.	3	10%
58	Amount of payment deduction for non-compliance product.	5	16%
59	Fairness of the method adopted by the MOC for deduction.	6	19%
*	**Out of 31 responses.**		

Figure 4.5 - Histogram - Factor Occurance



c) Delay in contractor progress payment:

Delay in contractor progress payment has been shown to have a level of effect on the pavement's quality (Table 4.4).In Table 4.11, eight (8) contractors indicated that this factor does occur in the Kingdom. Since the contractor depends on borrowed money to finance his operation, progress payment is very important to keep his working capital and cash flow at an adequate level. Delay in progress payment mostly occurs in public projects because of the many approval steps needed before the payment is transferred to the contractor. When the contractor feels that his progress payment is being unreasonably delayed, an adverse relationship can develop which may affect the project's quality.

d) Qualification of the owner inspection team:

This factor has a major effect on the pavement's quality. Seven (7) contractors indicated that this is a factor which has occurred in the Kingdom (Table 4.11). During the construction phase, the MOC's inspection team is responsible for administering the construction process according to the approved contract's documents with the assurance that the MOC receives acceptable work for the funds expended. Lack of experience in the team may lead to inconsistencies in an inspector's interpretation and conflict and claim between the project's, parties affecting the pavement's quality.

e) Contractor's characteristics:

Both a contractor's financial status and his labor and equipment capability are factors having a level of effect on the pavement's quality. In Table 4.11, six (6) contractors indicated that the first factor has occurred in the kingdom, whereas four (4) contractor's indicated that the second factor has occurred. Both the contractor's labor and equipment capability, and his financial status are among the main contractor's resources in efficiently performing the construction operations, and in developing better and more economical ways to accomplish the work to its desired quality. These are of special importance to the Kingdom since it encompasses different areas, i.e. sand dune areas, mountainous areas, and sabkha areas, with the various design, specification and construction challenges in pavement construction in these areas.

4.7.2- Design and Specification Factors:

a) Pavement design

Pavement that is not designed to the regional conditions (i.e. traffic, climate,...etc.) has the highest EIN value (93.35%). In Table 4.11 there are eight (8) contractors who have indicated the occurrence of this factor in the Kingdom. It makes no difference how carefully the construction process is performed if the design is defective. Because of the special traffic and environmental (temperature and soil type) conditions in the Kingdom, the process of transferring Western design methods and standards in pavement design have incurred many cases of road pavements that were too expensive and yet failed too early.

b) Design Error and Insufficient Owner Involvement During Design Phase:

These two factors have been shown to have a major effect on pavement's quality. Table 4.11 shows that seven (7) contractors indicated the occurrence of these two factors in the Kingdom. Most design errors in large public projects result from design teams who do most of their design work abroad with little consideration of the local conditions. On the other hand, because of the complexity associated with large public projects, such as highways, and the shortage of experienced engineers, owners usually limit their involvement during the design phase to the final design approval.

c) Accuracy of Investigation on Soil Type:

This factor has been shown to have a major effect on the pavement's quality. Five (5) Contractor's indicated that this is a factor which has occurred in the Kingdom (Table 4.11). The Kingdom encompasses different area such as sand dune areas, mountainous areas and sabkha areas. Each area represents special challenges to both pavement designers and contractors, specially when the highway being constructed passes over these areas.

d) Accuracy of Data Related to Traffic and Climate and its Relation to the Material used:

These two factors are very important parameters in pavement structural and mixture design. In Table 4.5 traffic data have been shown to have a level of effect, whereas climate and its relation has been shown to have a major effect on the pavement's quality. In Table 4.11, four (4) contractors indicated that these two factors do occur in the Kingdom. A survey done a few years ago shows that the average gross and axle loads in the Kingdom exceed the maximum allowable limits in most of the developed countries. Such a fact makes the transference of the Western pavement design technology to the Kingdom a dangerous practices.

The Kingdom's climate is hot. The interaction of hot climate and heavy traffic has accelerated the rate of pavement deterioration on the Kingdom's highways.

e) Asphalt Specified Quality and Content:

Table 4.4 shows that asphalt quality has a major effect on the pavement's quality. Four (4) contractors indicated that this factor does occur in the Kingdom (Table 4.11). The asphalt cement grade used in mix production is 60-70 penetration. Because of the Kingdom's hot climate this grade has been considered to be too soft, specially for primary roads, and one of the main causes of pavement rutting in the Kingdom's highway.

f) Mix Design does not Consider the Local Condition:

This factor has a major effect on the pavement's quality as indicated by it EIN value in Table 4.5. In Table 4.11

four (4) contractors have indicated the occurrence of this factor in the Kingdom. Climate and traffic conditions in the Kingdom are far more severe than those encountered in most of the western countries. One of the causes of pavement rutting in the Kingdom's highway was identified to be material properties specified and mix design used for the asphalt pavement layers construction.

4.7.3- Construction Process Factors:

a) Aggregate Quality (E.g., Gradation, Shape, Type, etc.):

Aggregate quality is among the factors which have the highest EIN value (Table 4.6). In Table 4.11 six (6) contractors indicated that this factor does occur in the Kingdom. As far as the quality of aggregate for road construction is concerned, there are three distinct regions in the Kingdom representing different aggregate qualities. The western and northern have good quality aggregate, the central region has an average quality aggregate, whereas the aggregate quality in the eastern region is generally marginal. Variation in aggregate quality can result in problems in achieving the desired quality specially when standard aggregate specification is used in all of the Kingdom's regions. The contractor can also find difficulties in aggregate selection in regions where marginal aggregate are available.

b) Amount of Filler Materials in the Mixture:

This factor is also among the factors having the highest EIN values. Table 4.11 shows that six (6) contractors have indicated the occurrence of this factor in the Kingdom. The amount and type of filler material have an extreme influence on the mechanical properties of the asphalt mixture (i.e., softening point, resistance to permanent deformation, etc.). Since the pavement surface temperature might reached up to 70 degrees centigrade in the Kingdom's hot summer, and because of the relationship between the filler material and the mixture's softening point, the filler should be added in quantity resulting in a binder-filler softening point greater than 70 degree centigrade.

c) Quality Control performed by the Owner Team:

As shown in Table 4.6, this factor has a major effect on pavement's quality. Table 4.11 shows that five (5) contractors indicated that this is a factor which has occurred in the Kingdom. Quality characteristics used for pavement evaluation, sampling location determination and evaluation method are all very important parameters of a quality control program. During the construction daily inspection activity, the MOC's inspector selects sample locations based on his judgment. This approach will introduce bias regarding pavement quality evaluation. An experienced inspector can increase or decrease the chances that the material being evaluated meets the specification requirements by selecting sample locations where the materials either look good or bad. Also the contractor has no assurance that the quality control terms will be interpreted fairly. This could end with conflict, disagreements and claims between the parties.

4.7.4- Acceptance (Handing Over Procedure) Factors:

a) Evaluation practice used for product acceptance:

Table 4.7 shows that evaluation practices used for the product acceptance factor has a level of effect on the pavement's quality. Four (4) contractors indicated that this factor occurs in the Kingdom. Since the pavement is preliminarily accepted at the end of the project, a large quality of material could be found in non-conformance with the specification where correction is difficult and expensive. In addition, pavement evaluation at the end puts the contractor under the risk of receiving payment reduction for the entire project.

b) Fairness of the method adopted by MOC for payment deduction and amount of payment deduction for non compliance product:

Both of these two factors have been shown (Table 4.7) to have a level of effect on the pavement's quality. Table 4.11 shows that six (6) and five (5) contractors respectively have indicated occurrence of these two factors in the Kingdom.

The method used by MOC for payment deduction determination for asphalt pavement considers that all of the quality characteristics used for acceptance evaluation are equal. In other words, if there are 10 quality characteristics to be used for asphalt pavement acceptance, each quality characteristic represents 10% of the asphalt pavement layer's cost. When the variation on the quality characteristics being evaluated is greater than the limits, deduction is made from the quality characteristic cost. Because of the existing interrelationship between the asphalt pavement quality characteristics, the concept of considering that quality characteristics are equal may sometimes over-penalize lower quality pavement. This occurs when two or more different quality characteristics, such as aggregate quality and asphalt content, are judged independently by the payment schedule but they are actually correlated.

4.8- Other Factors Mentioned by the Respondents

In the questionnaire form, the respondents were asked to mention other factors, based on their opinion, which affect the quality of asphalt concrete pavement in the Kingdom. A few respondents have added new factors. These factors are:

1- Ability of the supervising team to solve the problem faced by the contractor.

2- Participation of the supervising team in correcting job mistakes very quickly.

3- Experience of the supervising team in site problems.

4- Level of cooperation between the supervising team and the contractor.

5- Difficulties of the specification and its flexibility in accepting alternatives.
6- Continuous change of the specifications during the construction phase.
7- Shortage of experienced and skilled labors. (Most of the skilled labor return home as the project is completed).

Some of the respondents have suggested some recommendations for improving the quality of asphalt concrete pavement in the Kingdom. These are:

1- Accurate traffic survey including type of vehicles, traffic density and traffic composition for any road to be constructed.
2- Controlling and monitoring traffic loading and tire pressure (specially for trucks).
3- Use of asphalt cement which resists the effect of high summer temperature.
4- Use of chemical additives to improve the asphalt cement properties.
5- Reduction in asphalt concrete layer thickness.
6- Pre-qualification of the consultant and contractor prior to awarding the contract.

These suggestions are valuable since all the respondents have had experience with local materials, environmental and traffic conditions and the pavement construction process in the Kingdom.

Chapter V

Summary, Conclusion and Recommendations

5.1- Summary

The Kingdom of Saudi Arabia is more than 2700 Km. in length and more than 1600 Km. in width. Such a large area requires a good road network to connect the Kingdom's regions and its main cities. Furthermore, the availability of a good road network is an essential element upon which the Kingdom's regions continued development of industrial, agricultural and commercial sectors depends. For these reasons, the Kingdom's road network developed more rapidly than that of most industrialized countries. This has been however, achieved, even so, the Kingdom encompasses such extremely variable environmental and terrain conditions that road designers and contractors were presented with a unique set of design and construction challenges on almost every road they constructed.

During the past few years some of the newly constructed asphalt concrete pavement layers on several of the Kingdom's highways have been experiencing some types of distress problems, such as premature rutting. Most of the rutting problems were traced to the asphalt wearing course and/or the asphalt base course. This distress problem has resulted in poor pavement performance and has limited the use of the road making it a safety hazard. Consequently, the MOC has been forced to pay higher maintenance costs and/or to reconstruct the pavement at an early age causing a lot of unnecessary expense.

It is concluded that there is a need to conduct a study to identify the various factors affecting asphalt concrete pavement in the Kingdom's highways during the construction process (i.e. the design and construction phases)from the local highway contractor's point of view since they are the ones who construct the Kingdom's road network. This study serves as basic research to help in establishing more detailed research in the future regarding the performance of the Kingdom's asphalt concrete pavement.

Chapter II represents the literature review of the factors affecting the quality of asphalt pavements. The factors are divided into four categories. These are Managerial, Design and Specification, Construction Process, and Acceptance. For each category several related factors were discussed in detail. The literature review shows that good asphalt pavement is the result of a) good planning including road alignment, soil and traffic survey and analysis of availability of material for construction; b) proper pavement structural design; c) proper material selection and mix design for asphalt mixture; d) good construction practices including plant operation and paving site process; and e) good quality control in each of these areas. A less than satisfactory performance in any of these areas can result in an asphalt pavement that will perform poorly.

The main objective of this study has been to identify factors affecting the quality of asphalt pavements on the Kingdom's highways. Chapter III illustrates the survey done to achieve this objective. Questionnaire forms were sent to all of the Kingdom's highway contractors. The questionnaire form consisted of two parts. Part I related to the respondent's company, where Part II listed the factors which may affect quality. The factors were divided into four groups (i,e.Managerial, Design and Specification, Construction Process, and Acceptance (Handing Over Procedure).

Each factor was given four possible answers to measure the degree of effect on quality. In addition, the respondents were asked to indicate whether such factor occur in the Kingdom. Sixty one (61) questionnaires were sent to the contractors' organizations; thirty one (31) were retained.

Chapter IV represents the analysis of the contractors' responses. An Effect Index was calculated to measure the degree of effect that a factor can have on the pavement's quality. For the occurrence of factors affecting the quality of asphalt pavement on the Kingdom's highways the contractors' answer frequency is used.

5.2- Conclusion

The survey analysis reveals that all contractors are aware of the degree of effect that the factors can have on the quality of asphalt concrete pavement. The calculated EIN value indicates that most of the factors have an effect ranging from "major effect" to "effect". Based on the contractor answers regarding factor occurrence in the Kingdom and the calculated EIN values, the following factors are considered to be those which affect the quality of asphalt pavement in the Kingdom's highway:

A- Factors with Major Effect:

1) Clarity of responsibility and authority allocated to each party involved during the construction process.
2) Qualification of the owner inspection team.
3) Pavement not designed to the regional conditions.
4) Design errors from inaccurate assumptions, data,..etc.
5) Aggregate quality used (i.e. gradation, shape, ...etc.).
6) Asphalt quality.
7) Mix design not considering local conditions.
8) Climate and its relation to the material used.
9) Accuracy of investigation of soil type.
10) Amount of filler material used in the mixture.
11) Quality control procedure performed by the owner team during construction.

B- Factors with a level of Effect :

1) Selection of the lowest bidder to construct the projects.
2) Contractor's experience, labor and equipment capability.
3) Delay in contractor progress payment.
4) Accuracy of data related to traffic.

5) Insufficient owner involvement during the design phase.

6) Evaluation practices used for product acceptance.

7) Amount of payment deduction for non-compliance product.

8) Fairness of the method adopted by the MOC for deduction.

Based on the hypothesis test regarding the agreement between all contractors' grades, The test result has shown that all contractors' grades agreed on all of the factors' EIN values affecting the quality of asphalt pavement in the Kingdom's highways.

5.3- Recommendations

Designing and constructing a quality asphalt pavement is not a simple matter. For an asphalt pavement to perform to its potential, it is necessary to dedicate the time and effort required to do a quality job in each of the critical phases of design and construction of the pavement. The following points are recommended for the achievement of good quality asphalt pavement in the Kingdom's highways:

1- Quality is the product of a team effort. The contract document should shape the contractual relationship between the project's parties, defining in a clear manner the authority and responsibility of each party. This will lead in a cooperation between the parties in which efforts are focused on achieving the specified quality.

2- The owner site inspection team should be qualified enough to visually verify that good quality materials are incorporated into the pavement and that good construction practices are followed to achieve a good pavement quality. Training programs can be very effective in counteracting inspector's lack of experience.

3- The contractor awarded the contract should be selected on the basis of his experience, past performance on highway construction projects in the Kingdom, labor and equipment capability and not only the bid price. This is of a great importance to the Kingdom since it encompasses different areas which represent specific construction challenges to the contractor. Proper prequalification of the contractors is essential to ensure that the selected contractor is suited for the project being constructed.

4- For the pavement's structural design, Western design criteria and standards must be adequately re-evaluated for any necessary modification to reflect the Kingdom's unique traffic, climate, and terrain conditions. The pavement structural design should subjected to peer review to reduce the risk of inaccurate assumption and to ensure a quality design.

5- The Kingdom's traffic and climate conditions are far more severe than those encountered in Western countries. Asphalt mixture should be designed to suite the Kingdom traffic and climate conditions.

6- Aggregate material represents up to 90 - 95 percent by weight of the asphalt mixture. Improvement in the aggregate selection method and processing (crushing), specially in regions where marginal aggregate is available, can result in an improvement in the quality of the asphalt pavement at lower cost .

7- The asphalt cement grade used in asphalt mix production is the 60-70 penetration. For the Kingdom's hot climate this grade is a soft one. Improvement in asphalt quality through using a harder grade or chemical additives could lead to improvement in the mixture properties.

8- Adequate quality control is essential to assure the desired end product quality. Sample location must be randomly selected. Statistical techniques should be used in interpreting the test results performed on the random samples. This is to obtain an accurate estimation of the variability associated with the materials and the construction process as well as to eliminate bias introduced from the inspector.

9- A properly developed acceptance procedure is essential to determine the quality being achieved. The acceptance procedure should be developed with a through understanding of the risks involved with the acceptance decision.

10- Handing over procedure should be based on lot by lot acceptance approach. A contractor receiving a payment reduction in the first lot can make any necessary adjustment to his production process in an effort to avoid payment reduction on the subsequent lots. The MOC will be able to know immediately wither the contractor process is in accordance with the contract or not.

11- A statistical acceptance plan can be very effective in describing the quality characteristics that are desired from test results on random samples taken during the acceptance phase. Then depending on the degree of compliance, payment reduction can be used to award the appropriate payment level.

12- The magnitude of the payment reduction must be related to the effect of accepting material of less than desired quality. A better understanding of the relationship between material quality and pavement performance is necessary for the development of an adequate payment deduction for lower quality levels.

5.4- Recommendation for Future Studies

The owner, consultant, material processor and the contractor as members of the building team all have responsibilities in ensuring an adequate level of quality in the constructed pavement. The results of this research suggest the following areas which could be recommended for future research:

1- The same research but surveying the highway consultant firms in the Kingdom

2- Development of prequalification criteria for highway consultant and contractor selection.

3- Evaluation of the pavement design methods for highway project construction in the Kingdom.

4- A study of the aggregate production process and its effect on the asphalt pavement quality.

5- MOC inspection quality control program in pavement construction in the Kingdom.

6- Developing a statistical quality control to be implemented by the owner team during the construction phase.

7- Evaluation of the acceptance procedures used by MOC and the effect of acceptance of substandard quality on long term performing.

8- Lot by lot acceptance procedure and its implementation in the Kingdom's pavement construction projects.

9- Development of the payment adjustment system for acceptance of low quality material.

Appendixes

Appendix A

Questionnaire Form
Arabic and English

بسم الله الرحمن الرحيم

Ministry of Higher Education

King Fahd University of Petroleum & Minerals

وزارة التعليم العالي

جامعة الملك فهد للبترول و المعادن

١٤١١/٦/٢٣ هـ

السادة/ المحترم

السلام عليكم و رحمه الله و بركاته ، و بعد :

نفيدكم أن قسم هندسه و إداره التشيد بكليه تصاميم البيئه بجامعه الملك فهد للبترول و المعادن بالظهران يقوم بإعداد بحث دراسي علمي عن العوامل المؤثـــره على جوده الطرق ـ الطبقات الأسفلتيه ـ في فتره الانشاء في المملكـــه العـربيـــه السعوديه حيث أن الغرض من هذه الدراسه هي توضيح ومعرفه طبيعه تاثير تلك العوامل على جوده الطرق وذلك من أجل الصالح العام .

نأمل منكم المشاركه والإجابه على كافه الأسئله و موافاتنا بالمعلومات الضروريه للعوامل المؤثره وذلك لمعرفه أهميتها وتقييمكم لتلك العوامل ، ونحن سوف نقـوم بتجميع المعلومات من كافه مقاولي الطرق بالمملكه ، حيث أن نتائج هذا الأستبيـان سوف توضع في بحث لنيل درجه الماجستير .

نرجوا تحري الدقه و الواقعيه في الإجابات حيث معلوم لدينا بأهميه وقتكم ولكن مشاركتكم في هذا البحث ذو أهميه بالغه لعمل هذه الدراسه ، لذا نرجـوا منـكـم التكرم بإحاله هذا الإستبيان إلى مهندس ذو خبره جيـده في هذا المجـــال . كمـــا أن الإجابه على أسئله الإستبيان تتكون من جزئين هما :

الجزء الأول : معلومات عامه عن مؤسستكم أو شركتكم الموقره .

الجزء الثاني : العوامل المؤثره على جوده الطرق ـ الطبقات الأسفلتيه ـ في فتـــره الإنشاء في المملكه العربيه السعوديه .

نأمـل منكم التعاون معنا في سرعـه الإجابه علـى الإستبيان. ..... وتقبلوا خالص تحياتنا ،،

<u>ملاحظه : هنالك نسختين لهذا الإستبيـان آحداهما باللغه العربيه و الإخرى باللغه الإنجليزيه . الرجاء الإجابه على إحداهما فقـط .</u>

العنوان :- المهندس / محمد عبدالحميد الحسن

جامعة الملك فهد للبترول والمعادن

كلية تصاميم البيئة / هندسة وادارة التشييد

الظهران ٣١٢٦١ المملكة العربية السعودية

الباحث

السيد / محمد الحســن

المشرف على البحث / الدكتور عبد العزيز بوبشيت

هندسة وادارة التشييد

Construction Engg. & Mgt.

بسم الله الرحمن الرحيم

وزارة التعليم العالي
جامعة الملك فهد للبترول والمعادن

Ministry of Higher Education
King Fahd University of Petroleum & Minerals

التاريخ: ١٤١١/٠٨/٢٤هـ

السادة / المحترمين

السلام عليكم ورحمة الله وبركاته

ألحاقا لخطابنا الموءرخ بتاريخ ١٤١١/٠٦/٢٣ هـ والمرفق به الاستبيان الخاص ببحث العوامل الموءثرة على جودة الطرق - الطبقات الاسفلتية - في فترة الانشـــاء في المملكة العربية السعودية •

ونظرا أنه لم يصلنا الاستبيان المذكور حتى تاريخه وحيث أن مشاركتكم في تعبئة الاستبيان تشكل عنصرا رئيسيا في نجاح البحث وتطبيقه •

لذا نأمل التكرم بالتعاون معنا في تعبئة الاستبيان المرفق صورته أذا لم يتم تعبئته من قبل ومن ثم أعادته الى العنوان التالي في موعد أقصاه ١٤١١/١٠/٢٠هـ

المهندس/ محمد عبدالحميد الحسن
جامعة الملك فهد للبترول والمعادن
كلية تصاميم البيئة /هندسة وأدارة التشييد
الظهران ٣١٢٦١ - المملكة العربية السعودية

شاكرين لكم حسن تعاونكم معنا ،،،،

الباحـــث

السيد/ محمـــد الحســـن

المشرف على البحث الدكتور/عبدالعزيز بوبشيت

(اختياري)

أسم الشركة : ....

موقع الشركة الرئيسي : ....

عدد الفروع : ....

منصب المشارك في الإستبيان :............................

عدد السنوات في المنصب : ....

I – معلومات عامة عن الشركة :

١ – تصنيف الشركة حسب تصنيف وزارة الإسكان والأعمال العامة :

أ – ٥ ( )   ب – ٤ ( )   ت – ٣ ( )   ث – ٢ ( )   ج – ١ ( )

٢ – عدد السنوات في مشاريع السفلتة في المملكة العربية السعودية :

أ – أقل من ٥ سنوات ( )   ب – من ٥ – ١٠ سنوات ( )

ت – من ١٠ – ١٥ سنة ( )   ث – من ١٥ – ٢٠ سنة ( )

ج – أكثر من ٢٠ سنة ( )

٣ – عدد موظفي الشركة

أ) أقل من ١٠٠ عامل ( )   ب – من ١٠٠ – ٣٠٠ عامل ( )

ت) من ٣٠٠ – ٥٠٠ عامل ( )   ث) – من ٥٠٠ – ١٠٠٠ عامل ( )

ج) أكثر من ١٠٠٠ عامل ( )

٤ – معدل حجم الاعمال في السنة بالريالات السعودية (بالمليون ريال)

أ –أقل من ١ مليون ( )   ب – من ١ – ٥ مليون ( )

ت –من ٥ – ١٠ مليون ( )   ث – من ١٠ –٢٠ مليون ( )

ج –من ٢٠ – ٥٠ مليون ( )   ح – أكثر من ٥٠ مليون ( )

٥ – معدل مدة الاعمال :

أ – أقل من نصف سنة ( )   ب – من $\frac{1}{2}$ – ١ سنة ( )

ت –١ – ٢ سنة ( )   ث – ٢ –٣ سنة ( )

ج – أكثر من ٣ سنة ( )

II ماأثر العوامل التالية على جودة الخرسانة الأسفلتية للطرق في السعودية ؟

العوامل	مؤثر جداً	مؤثر	مؤثر بسيط	غير مؤثر	هل هذه مشكلة موجودة بالسعودية
أ – العوامل الإدارية : ١ – وضوح تحديد المسئوليات والصلاحيات لكل شخص يشارك في انشاء المشروع (المقاول والإستشاري-المراقب...الخ)					
٢ – كفائة الجهاز المشرف للمالك .					
٣ – ألمام ومعرفة فريق المالك بوثائق عقد المشروع وعملية الانشاء، وأخذ العينات وإجراء الفحوصات					
٤ – تخصيص مسئولية مراقبة الجودة للإستشاري .					
٥ – تقييم المقاول خلال عملية العطاء .					
٦ –اختيار المقاول ذو العطاء الأقل .					
٧ – خبرة المقاول السابقة .					
٨ – الحالة المالية للمقاول خلال الانشاء .					
٩ – مقدرة المقاول من ناحية الأيدي العاملة والمعدات .					
١٠ – كمية الأعمال المطروحة للتعاقد من الباطن .					
١١ – الارتفاع الغير منتظم لتكلفة المواد والايدي العاملة والمعدات المطلوبة لتحقيق مستوى الجودة المرغوبة .					
١٢ – عدم توفر الحوافز المالية للمقاول لإنتاج مستويات عالية الجودة .					
١٣ – التأخر في المدفوعات المالية الدورية للمقاول .					
ب – عوامل التصميم والمواصفات : ١٤ – عدم تصميم رصف الطريق حسب الظروف الإقليمية للمنطقة (نوع التربة، الحرارة، جودة المواد، حجم المرور) .					
١٥ – الأخطاء التصميمية الناتجة من إفتراضات المهندس الغير ملائمة ومعلومات غير مدققة..إلخ.					
١٦ – المشاركة الغير كافية للمالك في فترة التصميم (تقييم التصاميم، المراجعة، تعديل التصميم..إلخ					
١٧ – دقة الاستقصاء والتحقيق المجرى على نوعيات التربة المصادفة .					
١٨ – دقة المعلومات المتعلقة لحجم المرور، تركيبه، النمو المتوقع .					
١٩ – المناخ – الحرارة – وعلاقتها بالمواد المستخدمة .					

العوامل	مؤثر جداً	مؤثر	مؤثر بسيط	غير مؤثر	هل هذه المشكلة موجودة بالسعودية
٢٠-إستخدام الخرسانة الأسفلتية في إنشاء طبقات الرصف (تحت الأساس - الأساس - الطبقة السطحية).					
٢١- تماسك وإنتظام عملية تفسير المواصفات بالنسبة إلى: أ- جودة وتدرج الحصى.					
ب- جودة ونوعية الأسفلت.					
ج- نوعية الخلطة الأسفلتية.					
د- نسبة الدك أو الهرس.					
٢٢- مستوى التفصيلات الفنية المطلوبة لوصف المنتج ذو الجودة المرغوبة					
٢٣- الأفراط في وصف المواد والمعدات المستخدمة وعملية الانشاء المتبعة.					
٢٤- التقيدات على مصدر المواد، نوع المعدات، وطريقة الانشاء التي تفرض بواسطة المواصفات.					
٢٥- عدم اعتبار الشروط المحلية (الحرارة، المرور) عند تصميم الخلطة					
٢٦- الطريقة المستخدمة محلياً لعمل تصميم الخلطة.					
٢٧- إستخدام معادلة خليط العمل ذات تدرج كثيف لإنتاج المزيج الأسفلتي.					
٢٨- إستخدام معادلة خليط العمل ذات تدرج مفتوح لإنتاج المزيج الأسفلتي.					
٢٩- سعة هوات الفروق المسموح بها لمعادلة خليط العمل.					
٣٠- خواص المزيج الأسفلتي (التحمل، الثبات ..إلخ)					
ج - عوامل عملية الإنشاء: ٣١- طرق مراقبة الجودة المتبعة من قبل فريق المقاول في فترة الانشاء.					
٣٢- طرق مراقبة الجودة المتبعة من المقاول للمواد المخزنة في معمل الخلط.					
٣٣- تقييم المالك لمصادر المواد للمقاول.					
٣٤- توفر المواد ذات الجودة الموصوفة (الحصى، الأسفلت).					

العوامل	مؤثر جداً	مؤثر	مؤثر بسيط	غير مؤثر	هل هذه المشكلة موجودة بالسعودية
٣٥-تجانس المواد في المصدر (تدرج الحصى ، نـــوع الأسفلت).					
٣٦- عملية تكسير الحصى المتبعة في المحاجر .					
٣٧-جودة الحصى (التدرج - الشكل - النوع ... إلخ).					
٣٨-نوع الأسفلت وجودته .					
٣٩- الإختلاف في تدرج الحصى في المخزون ، في عملية الخلط ، النقل ، وعملية الرصف .					
٤٠- الإختلاف في محتوى الأسفلت خلال عملية انتاج المزيج الأسفلتي					
٤١- كمية الحشوة -المواد الناعمة- في المزيج الأسفلتي					
٤٢- التغيير المستمر في تصميم الخلطة بسبب التغيير في طبيعة ومصدر المواد خلال فترة الانشاء .					
٤٣- إستخدام مواد ذات مواصفات قريبـــــة من الحد الأدنى في مناطـــــق ذات مناخ حار ، ومرور ذو حمولات ثقيلة .					
٤٤- مراقبة عملية الخلط (مدة الخلط ، الحرارة ، دخول المواد لوحدة الخلط. الخ)					
٤٥ -عدم توفر أشخاص ذوي خبرة (مهندس مواد ، مراقب موقع ... الخ) في كل من فريـــق المقاول والمالك .					
٤٦- حالة سطح القاعـــــدة المراد تغطيتها بالطبقات الأسفلتية.					
٤٧- إنتظام عملية وضـــع المزيج الأسفلتي وعملية الدك أو الهرس .					
٤٨- الحالة الميكانيكية ونوع كل من الرصافة والهراس .					
٤٩- نمط الدك المتبع للوصول لكثافة الرصف المرغوبة.					
٥٠- مهارة وخبرة سائق الهراسة لملاحظة سلوك المزيج الأسفلتي تحت الهراسة					
٥١- الدك في الوقت الخاطيء .					
٥٢-الإفراط في عملية الدك .					
د - عوامل إستلام المشروع : ٥٣-طريقة التقييم المتبع لتحديد درجة قبول المشروع					
٥٤-كفاءة الأشخاص القائمين بعملية القبول أو إستلام المشروع.					
٥٥-كمية المبالغ المحسومة لمعاقبة المقاول للأعمال الغير مطابقة للمواصفات .					
٥٦-عدالة الطريقة المتبعة من قبل الوزارة لحساب المبالغ المحسومة.					

عوامل أخرى تتفضل بتحديدها	مؤثر جداً	مؤثر	مؤثر بسيط	غير مؤثر	هل هذه المشكلة موجودة بالسعودية

بســــــم الله الرحمن الرحيم

Ministry of Higher Education

King Fahd University of Petroleum & Minerals

وزارة التعليم العالي

جامعة الملك فهد للبترول والمعادن

Mr. Mohamad Al-Hassan
C/o Dr. A. Bubshait
KFUPM P.O. Box 960
Dhahran 31261
Saudi Arabia

9 January, 1991

Dear Respondent:

The Construction Engineering and Management Department of the College of Environmental Design at King Fahd University of Petroleum and Minerals is presently engaged in a study of identifying the essential factors that affect the quality of the asphalt concrete pavement (asphalt concrete layer only).

The purpose of the study is to identify the essential factors affecting the quality of the constructed asphalt concrete highway pavement in Saudi Arabia. The results of this study will be written in Master Degree research.

We will appreciate your participating by providing needed information related to the factors affecting the qualtiy of the pavement and your suggestions for improving the quality of asphalt concrete pavement in future projects.

All data of individual will be held in strict confidence.

We know that there are numerous demands on your time, but your involvement is important in contributing to the study. We will appreciate your help by letting the most experienced engineer in the company answering the questionnaire.

We shall, therefore, highly appreciate your kindness towards us in rendering the information as per our needs. Your contribution in this regard is highly appreciated.

Thank you in anticipation for your cooperation and understanding.

Sincerely yours,

M. Al-Hassan
Researcher

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450

Company Name: (Optional)____

Location of Main Office:____

No. of Branches____

Position of the Respondent:____

No. of Years in the Position:____

I. Information about the Respondent's Firm:

1. Company grading (classification) based on the grades specified by the Ministry of Housing and Public Works

   (a) 5
   (b) 4
   (c) 3
   (d) 2
   (e) 1

2. Number of years in the pavement construction industry in Saudi Arabia.

   (a) Less than 5 years
   (b) 5-10 years
   (c) 10-15 years
   (d) 15-20 years
   (c) More than 20 years

3. Number of employees

   (a) Less than 100
   (b) 100-300
   (c) 300-500
   (d) 500-1000
   (c) More than 1000

4. Average job size (millions of Saudi Riyals)

   (a) Less than 1
   (b) 1-5
   (c) 5-10
   (d) 10-20
   (e) 20-50
   (f) More than 50

5. Average job duration (years)

   (a) Less than 1/2
   (b) 1/2-1
   (c) 1-2
   (d) 2-3
   (e) More than 3

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II. WHAT EFFECT DO THE FOLLOWING FACTORS HAVE ON THE QUALITY OF ASPHALT CONCRETE PAVEMENT?

M.E = Major Effect   E = Effect   S.E = Some Effect

N.E = No Effect   * = Does this factor occur in Saudi Arabia

	FACTORS	M.E	E	S.E	N.E	*
	A - MANAGERIAL					
1	Clarity of responsibilites and authorities allocation of each member participating in the project construction phase (contractors, consultant, inspectors... etc.).					
2	Qualification of the owner's inspection team.					
3	Owners team familiarity with the project contract document, construction process, sampling and testing procedures.					
4	Assignment of quality control responsibility to the consultant,					
5	Qualification of contractors during bidding process.					
6	Selection of the lowest bidder to construct the project.					
7	Contractor's previous experience.					
8	Contractor's financial status during construction.					
9	Contractor's labor and equipment capability.					
10	Amount of work sub-contracted.					
11	Cost escalation of material, labor and equipment needed to achieve the required quality level.					
12	Unavailability of financial incentives for contractor to produce higher quality level.					
13	Delay in contractor progress payment.					
	B - DESIGN AND SPECIFICATION					
14	Pavement is not designed to the regional conditions (e.g. soil type, temperature, material quality, traffic,... etc.).					
15	Design errors arising from inadequate engineer assumptions, inaccurate data,...etc.					
16	Insufficient owner involvment during the design phase (e.g. design evaluation, review, updating design,... etc.).					
17	Accuracy of investigation performed on soil type encountered.					
18	Accuracy of data related to traffic volume, compostion and expected growth.					
19	Climate (temperature) and its relation to materials used.					
20	The use of full depth asphalt concrete cross-section.					
21	Consistency of specification interpretation of aggregate guality & gradation .					
22	Consistency of specification interpretation of Asphalt guality &content .					
23	Consistency of specification interpretation of Mixture compostion.					
24	Consistency of specification interpretation of Compaction level .					
25	Level of technical details required to specify the desired product quality.					
26	Over-specifying of materials and equipment to be used, and construction techniques to be followed.					
27	Limitation on material source selection, equipment type, construction method...etc. imposed by the specification.					
28	Mix design does not consider the local conditions (temperature and traffic...etc.).					
29	Mix design method used locally.					
30	The use of dense graded job mix formula for mixture production.					

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	M.E = Major Effect E = Effect S.E = Some Effect N.E = No Effect * = Does this factor occur in Saudi Arabia	M.E	E	S.E	N.E	*
	FACTORS					
31	The use of open graded job mix formula for mixture production.					
32	Wide job mix formula tolerances.					
33	Asphalt mixture properties (e.g. stability, durabilty,...ect.).					
	C - CONSTRUCTION PROCESS					
34	Quality control procedure (i.e. testing, sampling and inspection) performed by the owner team during construction phase.					
35	Contractor's quality control for material at mixing plant stockpiles.					
36	Owner's evaluation of the contractor's material source.					
37	Availability of the specified material quality (e.g. aggregate asphalt).					
38	Uniformity of material at source (ie. Aggregate gradation - asphalt grade).					
39	Aggregate crushing process at material source.					
40	Aggregate quality (e.g. gradation, shape, type,...etc.).					
41	Asphalt grade and quality.					
42	Variation on aggregate gradation in stockpiles, mixing, transportation and placement operation.					
43	Variation on asphalt content during mixture production.					
44	Amount of filler materials in the mixture.					
45	Continuous changing in mix design due to change in the nature and source of aggregate during construction phase.					
46	The use of marginal material in pavement construction in regions of hot climate and heavy loading traffic conditions.					
47	Monitoring mixing operations (e.g. mixing time and temperature, material feeding etc.).					
48	Lack of experienced staff (e.g. material engineer, site supervisor,... etc) on contractor and owner team.					
49	Condition of road bed soil.					
50	Uniformity of mixture placement and compaction operations.					
51	Paver and roller mechanical condition and type.					
52	Compacting pattern used to achieve the desired pavement density.					
53	Roller driver experience and skill to observe mixture behavior under roller.					
54	Compaction at wrong time.					
55	Over - compaction .					
	D - ACCEPTANCE(Handing over procedure)					
56	Evaluation practices used to determine the degree of acceptability of the product.					
57	Qualifiction of the people performing acceptance procedures.					
58	Amount of payment deduction to penalize the contractor for non-compliance product.					
59	Fairness of the method adopted by the MOC for deduction calculations.					
	Other factors you would like to specify.					

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Appendix B

Highway Construction (Contractor List in Saudi Arabia)

Ministry of Higher Education

King Fahd University of Petroleum & Minerals

وزارة التعليم العالي

جامعة الملك فهد للبترول والمعادن

التاريخ: ١٨ ربيع الاول ١٤١١ هـ

السادة/ قسم تنفيذ المشاريع بوزارة المواصلات المحترم

السلام عليكم ورحمة الله وبركاته

نفيدكم أن قسم هندسة وإدارة التشييد في كلية تصاميم البيئة بجامعة الملك فهد للبترول والمعادن يقوم بإعداد بحث دراسي علمي عن العوامل المؤثره على جودة الطرق (الطبقات الإسفلتيه) حيث أن الغرض من هذه الدراسه هو توضيح ومعرفة طبيعة تأثير تلك العوامل على جودة الطرق في المملكة العربية السعودية وذلك من أجل الصالح العام ٠

وحيث أن البحث يتطلب إرسال إستبيانات للأشخاص المعنيين بتنفيذ مشاريع الطرق في المملكة لذى نرجوا منكم تزويدنا بأسماء وعناوين الشركات أو المؤسسات (المقاولين) المنفذين لمشاريعكم في جميع مناطق المملكة ٠

نأمل منكم المساعدة في هذا المجال ٠

وتقبلوا مسبقاً كامل شكرنا وتقديرنا ٠

١٨/٢/١٤١١هـ

الدكتور عبدالعزيز عبدالرحمن بوبشيت
مدير برنامج هندسة وإدارة التشييد
كلية تصاميم البيئة

٨٥٧
١٤١١/٣/٢٠

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المملكة العربية السعودية

وزارة المواصلات

الاداره العامه للتنفيذ

الموضوع : اسماء وعناوين المقاولين مع وزارة المواصلات .

المكرم الدكتور عبدالعزيز بو بشيت ـ كلية تصاميم البيئه المحترم

جامعة الملك فهد للبترول والمعادن

بعد التحيه :

أشير الى خطابكم المرفق المؤرخ ١٤١١/٣/١٨ بشأن طلبكم اسماء وعناوين الشركات والمؤسسات المنفذه لمشاريع هذه الوزاره في جميع انحاء المملكه .

أرفق لكم من طيه اسماء وعناوين المقاولين العاملين في مشاريع انشاء ورصف الطرق العائده لوزارة المواصلات وحسب طلبكم .

ولكم تحياتنا .،،،

مدير عام التنفيذ

م/على بن عبدالله النعيم

make one copy
and keep the
original in the
Research file

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الرقم ٨٠٩

التاريخ ٢٣/٤/١٤١١هـ

المرفقات اسماء وعناوين المقاولين

	الاسم	رقم صندوق البريد	الرمز	المدينة	
١	شركة محمد العلي السويلم للتجارة والمقاولات	٢٦٢٥٠	١١٤٨٦	الرياض	
٢	مؤسسة محمد العلي السويلم للتجارة والمقاولات	٤١٨١	١١٤٩١	"	
٣	مؤسسة عبدالله بن قدران	٢٠٧٦٤	١١٤٦٥	"	
٤	الشركة العربية للمقاولات الفنية (آرتك)	١٢٨٧	٢١٤٢١	جدة	
٥	شركة الإنارة السعودية	٢٥٦٠٩	١١٤٧٦	الرياض	×
٦	" صقر للمشاريع	٥٢٥٨٩	١١٥٧٣	"	
٧	مؤسسة عبدالعزيز العريني للمقاولات	٣٢٦٠	١١٤٧١	"	
٨	" البعيجي للمقاولات	٥٩٩٨	١١٤٣٢	"	
٩	شركة الجهاد السعودية	٣٦٩٧	١١٤٨١	"	
١٠	مؤسسة البدور للمقاولات العامة والتجارة	٦٧٤٦	١١٩٥٢	"	
١١	" العيوني للتجارة والمقاولات	٤٧٢٧	١١٤١٢	"	
١٢	" محمد بن لادن للمقاولات	١٠٥	١١٤١١	"	
١٣	" عبدالعزيز محمد خضري	١١٥١٦	٢١٤٦٣	جدة	
١٤	شركة برمة للتجارة والمقاولات	٨٨١	—	بريدة	
١٥	" المشرق للمقاولات	٦١٠٨	١١٤٤٢	الرياض	
١٦	مؤسسة باحمدين للتجارة والصناعة والمقاولات	١١٧٠	٢١٤٢١	جدة	
١٧	" انشاء الفرقد	٥٠٢٣	٣١٩٥٢	الخبر	
١٨	مؤسسة كرا للمقاولات	١٣٠٦٣	١١٤٢١	الرياض	
١٩	شركة مسعود وعمر الحديرس	٨١٨٨	١١٤٨٢	"	
٢٠	مؤسسة عبدالله بن قدران	٢٠٧٦٤	١١٤٦٥	"	مكرر

	الإسم	رقم صندوق البريد	الرمز	المدينة
٢١	شركة ناصر بن العزاز واخوانه	١٢	—	الخبر
٢٢	مؤسسة شبه الجزيرة للمقاولات	٢٧٤٠	١١٤٦١	الرياض
٢٣	" بن جار الله للتجارة والمقاولات	٧٢ ٧٥٧٧	١١٤٧٢	خميس مشيط
٢٤	" الإقبال السعودية للدهانات	٢٧٧٥	١١٤٦١	"
٢٥	شركة الكاملين للتجارة والمقاولات	٥٤٥١	١١٤٢٢	"
٢٦	مؤسسة بن حمران للمقاولات	٣٨٩	—	خميس مشيط
٢٧	" يوسف الجريد للمقاولات	٧٢٧	١١٤٢١	الرياض
٢٨	شركة الزومير للتجارة والمقاولات	١٧٤٤٨	١١٤٨٤	"
٢٩	مؤسسة روكي للتجارة والمقاولات	٢٠٩٤١	١١٤٦٥	"
٣٠	" الحصيني للتجارة والمقاولات	٦٦٥٢	١١٤٥٢	"
٣١	" الفقاس للتجارة والصيانة والمقاولات والتعهدات	١٠٢ ٥٢٣٠٩ ١٤٢٩	١١٦٥١ ١١٤٢١	جيزان الرياض "
٣٢	شركة إتحاد التطوير والتنمية السعودية المحدودة	٨٨٢٥	١١٤٩٢	الرياض
٣٣	مؤسسة المسعد للطرق	٤٨٨٦	١١٤١٢	"
٣٤	" اجزال للتجارة والمقاولات	٤٩٢٤	١١٤١٢	"
٣٥	" الأسود للمقاولات	٥١٦٥	١١٤٢٢	"
٣٦	" الساند للمقاولات	٢١٥٤١	١١٤٨٥	"
٣٧	" العويضة للمقاولات	٤٢٣٨	١١٤٩١	"
٣٨	شركة صالح وعبدالعزيز أبا حسين	٢١٣٧١	١١٤٧٥	"
٣٩	شركة التضامن الفنية	٤٠٣٤	١١٤٩١	"
٤٠	" بيس الهندسية	٨٨٠٤	١١٤٩٢	"

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بيان بأسماء المقاولين العاملين مع هذه الوزارة وعناوينهم

	الإســـــم	رقم صندوق البريد	الرمز	المدينة
٤١	شركة جاكس للمقاولات والتعهدات	١٦١١	١١٤٤١	الرياض
٤٢	" الحرب للتجارة والمقاولات	٥٧٥٠	١١٤٢٢	"
٤٣	" الحسون للتجارة والمقاولات	٣٤٩٥	١١٤٧١	"
٤٤	مؤسسة الحميدي للمقاولات	١٣٠	١١٤١١	"
٤٥	شركة الحرمين للتجارة والمقاولات	٣٤٥٩	١١٤٧١	"
٤٦	مؤسسة عبدالله عبدالمحسن الخضري للمقاولات العامة	٣٨٩٤ ٨٣٢	١١٤٨١ ٣١٤٢١	الرياض الدمام
٤٧	" الدخيل وشركاهم	٢٠٨٨	١١٤٥١	الرياض
٤٨	شركة الراشد للعمران	٢٧٤٢ ٩٩	١١٤٦١	" الاحساء
٤٩	" " المنصور	١٦١٩١	١١٤٦٤	"
٥٠	" الوسيعة والمضمار	٢٨٨٩	١١٤٦١	"
٥١	" ريو للتجارة والمقاولات	٢٦٩٢	١١٤٨١	"
٥٢	" سام وأن	٥٧٤٣	١١٤٣٢	"
٥٣	" الشبانات والشنيفي	٢٠٩٣٢	١١٤٦٥	"
٥٤	" صفا للمقاولات	٢٩١٠	١١٤٦١	"
٥٥	مؤسسة الطرود للتجارة والمقاولات	٨٨٣٨	١١٤٩٢	"
٥٦	" العايد للتجارة والمقاولات	٤٠١٢٥	١١٤٩٩	"
٥٧	" الفهد للتجارة والصناعة والمقاولات	٥٤٤٥	١١٤٢٢	"
٥٨	شركة المحيسن للتجارة والمقاولات	٢٨٥٩	١١٤٦١	"
٥٩	" المدينة للمقاولات والتجارة	٤٧٤٦	١١٤١٢	"
٦٠	مؤسسة المصطفى للتجارة والمقاولات	٧٧٠٥	١١٤٧٢	"

بيان بأسماء المقاولين العاملين مع هذه الوزارة وعناوينهم

	الإســـــــم	رقم صندوق البريــــد	الرمــــز	المدينـــة
٦١	شركة محمد المرطان	١٥٨٥٠	١١٤٥٤	الرياض
٦٢	" الشمال للتجارة والمقاولات	١٨٤١	١١٤٤١	"
٦٣	مؤسسة الخضير للتجارة والمقاولات العامة	٢٢٩٨	١١٤٧١	"
٦٤	" أليلة للتجارة والمقاولات	٣٨٩٨	١١٤٨١	"
٦٥	شركة البابطين للتجارة والصناعة والمقاولات	١٨١	١١٤١١	"
٦٦	مؤسسة الجديبة	٣٤٤	٣١٩٥٢	الخبر
٦٧	شركة ابن حسين بالضمان مع الجهني	٨٦٠٥٩		الرياض
٦٨	مؤسسة عبدالهادي الجهني	٤٤٧		المدينة المنورة
٦٩	شركة الشيخ العرجاني	٦٧٦		الهفوف
٧٠	مؤسسة للتجارة والمقاولات	٢٥١٦	٣١٤٦١ ٣١٤٢١	الدمام
٧١	شركة الخليج للطرق	١٢٤٣		الهفوف
٧٢	شركة الفوزان لإنشاء الطرق	١٢٦٦	٣١٩٥٢	الخبر
٧٣	شركة الرباس للطرق والصيانة المحدودة	١٤١٩	٣١٩٥٢	الخبر

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Appendix C

* MOC's Computation of Deductions and Penalties Procedure (part H of the MOC's Handing Over Manual currently used).

* An example of payment deduction calculation for asphalt layers in one of the MOC's highway project Abu-Hadriyah Dammam Express Way No.1, Section "C".

H. COMPUTATIONS OF DEDUCTIONS AND PENALTIES

The Committee is required to check all the items of work to see whether the work is executed in accordance with the specific requirements of the project or not . In case some of the items show deviations from specifications, they can not be accepted until they are reworked to satisfy the requirements . In case the rework is not possible or it would affect the other items considerably then the safety of pavement structure should be studied . If it is found unsafe, some remedial measures or rejection should be proposed . If in the opinion of the Committee, the road structure is found safe and usable then the works can be accepted with appropriate deduction / penalty from the cost of the work, as detailed below :

1. Characteristics of the Various Roadway Elements to be Considered.

a. Asphalt Works

1. Aspahlt content as per Marshall design
2. Quality of Asphalt used, 60-70 or any other type
3. Quality of Asphalt mix (% Air Voids, VMA, VF, stability, etc.)
4. Quality of Aggregates
5. Grading of Aggregates
6. Compaction

b. Aggregate Base Course and Granular Subbase

1. Grading of Materials
2. Classification of Materials
3. Compaction
4. Quality of Aggregates
5. Strength (C.B.R.)
6. Sand Equivalent

c. Subgrade

1. Grading of Materials
2. Classification of Materials
3. Required Strength (C.B.R.)
4. Compaction

d. Embankment

1. Classification of Materials
2. Compaction
3. Workmanship

e. Concrete Works

1. Compressive Strength
2. Dimension
3. Workmanship

2. Percentage of Each Characteristics

Considering the unit price in the tender as 100 %, each characteristic should have an equal value to the other characteristics in the same item for example :

Number of Characteristics		% of Each Characteristics (rounded)
10	100 / 10	10
9	100 / 9	12
8	100 / 8	13
7	100 / 7	15
6	100 / 6	17
5	100 / 5	20
4	100 / 4	25
3	100 / 3	34

3. Instructions for Deductions

The Committee will make deductions for the portion represented by the samples not complying with the Specifications in the ratio proposed in this project . The Committee should view the results of test for each characteristic alone, and may tolerate the deficiency if only one sample is different at a non-significant ratio . However, if the samples not in compliance with specifications are more than 80 % , the whole length of the road should be deducted

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and not only 100 % of the sample since this is considered a rejection . Maximum deduction allowable is 99 % of what the sample represents . The following are some proposals for deductions :

a. Asphalt Content

Deduct 17 % of the ratio representing this charcteristic for 0.1 % deviation in asphalt ratio beyond the tolerable limits in Specifications, (Marshall +/- 0.3 %) . The Committee should run tests to check quality of asphalt mix like % Air Voids, VMA, VF, etc., and if need be , the maintenance period should be extended until one complete summer passes to see the effects on the road .

b. Quality of Materials

The quality of materials should be taken into account by the Supervisory Staff. The Committee should at least study this matter from the files to ensure that all required tests have been carried out . The main elements which should be noted are Abrassion and Adhesion of Asphalt .

c. Grading of Bituminous Mix or Earthwork

In evaluating results of grading it should be taken into account that whenever the sizes are finer their effect will be more critical on the final characteristics of the materials .

Therefore, the Committee should study the characteristics and compare them with other characteristics (i.e. in case of asphalt mix, ratio of asphalt in the bituminous mix, % air voids, VMA, VF, etc.) . It is propcsed that deductions be made on the following variations :

1.0 No deduction is made if few samples deviate in one sieve at a ratio of 1 % .

2.0 No deduction is made if there are few irregular samples with one coarse sieve at a ratio of 1 % and one fine sieve at a ratio of 1 % .

3.0 If more than one sieve varied from the Specifications in the same sample, the following deductions apply :

3.1 On each ratio of variation from Specifications a 3 % will apply for coarse materials, i.e., if the sample is varying form the Specifications in sieves 3/4", 3/8", and #4 by 3 %, 2 % and 5 % then these ratio are added (3+2+5=10 %) and this figure is multiplied by 3 so that the ratio become 30 % of the ratio representing the grading .

3.2 If the sample varies from Specifications in fine sieve, the ratio will be multiplied by five (5) instead of 3 . The fine sieve which have effect are sieve no.40 to sieve no.200 . It should be noted that if the ratio varying from Specifications reach an unacceptable limit the course for which the sample is representing shall be rejected .

3.3 If one sieve varies but this is repeated in other sample until it reaches 80 % of the samples, the committee should apply additional deductions because the Contractor

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did not modify the gradation to comply with the Specifications. The deduction will range between 30 - 50 % of the distance represented by the samples not in compliance with the Specifications .

3.4 If various sieves varied in samples to cover 80 % or more of total samples, an additional deduction of 20 - 40 % should be applied .

d. Compaction of Asphalt Mix or Earthwork

1. If only one sampled failed at a ratio not exceeding 1 % , this will be accepted wihout deduction .

2. Twenty (20 %) per cent will be deducted for every ratio less than the required Specifications provided that the total reaches a maximum of 99 % of the equivalent value of compaction .

3. If shortage was 5 % or more, the area represented by the sample will be rejected and shall be re-evaluated in the following manner :

a. Asphalt Works

The per cent air voids should be analyzed and the matter should be referred to the Ministry for evaluation and decision .

b. Earthworks

The strength of these layers will be tested and CBR test is carried out for actual compaction in the field, and the matter is referred to the Ministry for evaluation and decision .

4. If there is a shortage in the compaction ratio compared to what is required by the Specifications and the number of samples varying form Specifications exceeded 80 % of total samples taken, the Committee should apply deductions to the said element in the whole project .

e. Thickness

For shortage in thickness of direct value for each element (layer of the road) for the distance represented by the sample a deduction will be made, or such deduction be subject to the following :

1. One sample with slight shortage not exceeding 3mm. of the tolerable limit will be accepted without deduction .
2. A shortage in one layer may be compensated in the second layer provided that the variable coefficient of each layer be taken into account (surface course = 1, base course = 0.9) . Compensation should be of the same type .

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3. If the shortage is in the thickness of 80 % of the samples. deduction will be for the whole road on the basis of the average thickness for the whole project .

4. If the shortage is more than 1 cm. or 15 % whichever is the least, the matter shall be referred to the Ministry for evaluation and necessary action .

f. Conrete Works

Since strength, workmanship, and dimensions has a value equal to 1/3 of the tender price, the following assesment are taken into consideration :

1. Strength :

It is natural to take into consideration the quality of materials used in making the concrete to meet specifications requirements because the supervisory staff accepted the use of the materials in the mix . Also, the proportions of the materials may also affect the strength of the concrete . So the strength in this respect may represent the quality . Maximum shortage tolerable is 20 % of the specified strength . The tolerable ratio is 5 % out of the 20 % for every 1 % shortage in strength multiplied by one third . If the shortage is more than 20 %, the matter shall be referred to the Ministry for evaluation and necessary action .

3. If the shortage is in the thickness of 80 % of the samples. deduction will be for the whole road on the basis of the average thickness for the whole project .

4. If the shortage is more than 1 cm. or 15 % whichever is the least, the matter shall be referred to the Ministry for evaluation and necessary action .

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بسم الله الرحمن الرحيم

المملكة العربية السعودية
وزارة المواصلات

REPORT FOR PARTIAL
PRELIMINARY HAND-OVER
OF PROJECT ABU HADRIYAH-
DAMMAM EXPRESSWAY No.1,
SECTION "C"

تقرير عن الاستلام الابتدائي
الجزئي لمشروع طريق ابوحدرية -
الدمام السريع رقم : ١ الجزء
ج

CONSULTANTS : M/S TECNIC
CONTRACTORS : M/S CO.GE.CO.

الاستشاري : شركة تكنيك
المقاول : شركة كوجيكو

الموضوع :

In accordance with the administrative order No. 831 dated 13.3.1401 H. a committee of the following was formed for the partial preliminary hand-over of project Abu Hadriyah-Dammam Expressway No.1, Section "C" :

بناء على الامر الاداري رقم ٨٣١ وتاريخ ١٣/٣/١٤٠١هـ، تشكلت اللجنة التالية لاجراء الاستلام الابتدائي الجزئي لمشروع طريق ابوحدريه / الدمام السريع رقم : ١ الجزء " ج ".

I - FOR MINISTRY OF COMMUNICATIONS:

1. Eng.Mahmood Ahmad Gulam (Laboratory)
2. Eng.Abdul Aziz Abdul Jabbar (Laboratory)
3. Trainee Eng.Jameel Mohammad Hobani
4. Eng.Ibrahim Lim (Bridges)
5. Inspector Zaid Al Faiz (Laboratory)
6. Surveyor Fathi Hashem Al-Tokhi

اولا - عن وزارة المواصلات :

١ - المهندس محمود احمد غلام (المختبر)
٢ - المهندس عبد العزيز عبد الجبار (المختبر)
٣ - مهندس تحت التدريب جميل محمد حوباني
٤ - المهندس ابراهيم ليم (الجسور)
٥ - المراقب زيد الفايز (المختبر)
٦ - المساح فتحي هاشم الطوخي .

II- FOR CONSULTANTS M/S TECNIC:

1. Eng.S.Abdullah M.Alonto (R.E.)

ثانيا - عن الاستشاري شركة تيكنيك :

١ - المهندس اس.عبدالله م. الونتو (مهندس مقيم)

III-FOR CONTRACTORS M/S CO.GE.CO.:

1. MR.GIUSEPPE CELLINI (M.E.)

ثالثا - عن المقاول شركة كوجيكو :

١ - السيد / جيوسيبي تشيليني (مهندس مواد)

The committee studied the Consultants prehanding over report and proceeded to the site on 15.3.1401 H.

درست اللجنة تقرير الاستشاري السابق على التسليم ثم توجهت الى الموقع بتاريخ ١٥/٣/١٤٠١هـ

cont/2

٢ / يتبع

بسم الله الرحمن الرحيم

المملكة العربية السعودية
وزارة المواصلات

الموضوع :

The committee checked the project files for reference, made all the necessary field and laboratory tests, checked the concrete structures and checked the lines and grades of the project. The committee worked at site from 15.3.1401 H. to 2.4.1401 H.-The detailed recommendations are given below :

I - BITUMINOUS WEARING COURSE AND BITUMINOUS BASE COURSE CLASS "B" :

A) Thickness:

Thickness was checked by taking 123 cores from different stations as shown on the test hole location map representing the main road, the interchanges, the link roads and the shoulders.

Thickness was found to meet with the requirement at all stations except the following deficiencies :

S- 7 = -0.9 cm(Bit.Base Course)
S-11 = -0.1 cm(- do -)
B- 5 = -0.4 cm(- do -)
M- 5 = -0.9 cm(- do -)
S-28 = -1.0 cm(- do -)
S-29 = -0.5 cm(- do -)
B- 9 = -0.8 cm(- do -)
S-40 = -0.4 cm(- do -)
S-44 = -0.3 cm(- do -)

فحصت اللجنة ملفات المشروع للاضطلاع عليها ،ثم اجرت كافة الفحوص المختبرية الحقلية اللازمة وفحصت المنشآت الخرسانية ثم فحصت خطوط ومناسيب المشروع.

عملت اللجنة فى الموقع من ١٤٠١/٣/١٥هـ، وحتى ١٤٠١/٤/٢هـ.
وفيما يلى التوصيات التفصيلية :

اولا - طبقة السفلتة السطحية وطبقة الاساس البيتومينية صنف "ب".

أ - السماكة :

تم فحص السماكة باخذ ١٢٣ عينة قالب من مواقع مختلفة حسبما هو مبين فى مخطط موقع حفر الفحص التى تمثل الطريق الرئيسى والتقاطعات ووصلات الطرق والاكتاف.

وجدت السماكة مطابقة للمتطلبات فى جميع المواقع باستثناء النواقص التالية :

اس-٧ = ٩ر٠ سم (طبقة الاساس البيتومينية)
اس-١١ =-١سم (= = =)
ب-٥ =-٤سم (= = =)
أم-٥ =-٩ سم (= = =)
اس-٢٨ =-١سم (= = =)
اس-٢٩ =-٥ر٠سم (= = =)
ب-٩ =-٨ر٠سم (= = =)
اس-٤٠ =-٤ر٠سم (= = =)
اس-٤٤ =-٣ر٠سم (= = =)

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٣/ يتبع

الرقم .... التاريخ .... المرفقات ....

ملاحظة : يرجى فى حالة الرد الاشارة الى الرقم والتاريخ واعادة صورة الخطاب المرفقة

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المملكة العربية السعودية

وزارة المواصلات

الموضوع :

Sh-14 = -0.3 cm(Bit.Wearing Course)
Sh-20 = -0.4 cm(- do -)
Sh-33 = -0.7 cm(- do -)

Deficiencies at S-11,S-44 and Sh-14 are with the tolerance limits.The committee recommends to accept them without any deduction.

Deficiencies at other stations are minor and will not effect the utility and durability of the project.The committee recommends to accept them with following deductions :

Deduction= Deficiency x Length x x Width x Rate

S- 7=$\frac{0.9}{100}$ x1651x11.80x340= SR.59,614.31

B- 5=$\frac{0.4}{100}$ x1652x11.80x340= SR.26,511.30

M- 5=$\frac{0.9}{100}$ x1651x11.80x340= SR.59,614.31

S-28=$\frac{1.0}{100}$ x1651x11.80x340= SR.66,238.12

S-29=$\frac{0.5}{100}$ x area x rate =

=$\frac{0.5}{100}$ x $\frac{6150}{2}$ x 340 = SR. 5,227.50

كف - ١٤ = -٣ر٠سم (طبقة سفلتية سطحية .)
كف - ٢٠ = -٤ر٠سم (= = =)
كف - ٣٣ = -٧ر٠سم (= = =)

تقع النواقص في العينات اس - ١١ واس - ٤٤ وكف - ١٤ ضمن حدود الفروق المسموح بها . توصي اللجنة بقبولها دون اي حسم .

بالنسبة للنواقص في الاجزاء الاخرى فهي ثانوية وسوف لن تؤثر على الاستفادة من المشروع وقوة تحمله توصي اللجنة بقبولها مع تطبيق الحسميات التالية :

الحسم = النقص x الطول x العرض x معدل السعر

اس - ٧ = ٩ر٠/١٠٠ x ١٦٥١ x ٨٠ر١١ x ٣٤٠
= ٥٩ر٦١٤/٣١ ر.س

ب - ٥ = ٤ر٠/١٠٠ x ١٦٥٢ x ٨٠ر١١ x ٣٤٠
= ٢٦ر٥١١/٣٠ ر.س

ام - ٥ = ٩ر٠/١٠٠ x ١٦٥١ x ٨٠ر١١ x ٣٤٠
= ٥٩ر٦١٤/٣١ ر.س

اس - ٢٨ = ١ر٠/١٠٠ x ١٦٥١ x ٨٠ر١١ x ٣٤٠
= ٦٦ر٢٣٨/١٢ ر.س

اس - ٢٩ = ٥ر٠/١٠٠ x المساحة x معدل السعر =

= ٥ر٠/١٠٠ x ٦١٥٠/٢ x ٣٤٠ = ٥ر٢٢٧/٥٠ ر.س

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٤ / يتبع

الرقم .... التاريخ .... المرفقات ....

ملاحظة : يرجى في حالة الرد الاشارة الى الرقم والتاريخ واعادة صورة الخطاب المرافقة

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المملكة العربية السعودية
وزارة المواصلات

الموضوع :

$B\text{-}9 = \frac{0.8}{100} \times \frac{754}{0.12 \times 3} \times 340 = SR.5,696.89$　　ب - ٩ = ٨ر٠/١٠٠ × ٧٥٤/(١٢ر٠×٣) × ٣٤٠ = ٨٩/٦٩٦ر٥ ر.س

$S\text{-}40 = \frac{0.4}{100} \times \frac{401}{0.12} \times 340 = SR.4,544.67$　　س - ٤٠ = ٤ر٠/١٠٠ × ٤٠١/١٢ر٠ × ٣٤٠ = ٦٧/٥٤٤ر٤ ر.س

$Sh\text{-}20 = \frac{0.4}{100} \times 345.74 \times (2.50+1.50) \times 361 = SR.1,996.99$

$Sh\text{-}33 = \frac{0.7}{100} \times \frac{861.41}{3} \times (2.50+1.50) \times 361 = SR.2,902.38$

كف - ٢٠ = ٤ر٠/١٠٠ × ٧٤ر٣٤٥ × (٥٠ر٢ + ٥٠ر١) × ٣٦١ = ٩٩/٩٩٦ر١ ريال سعودى

كف - ٣٣ = ٧ر٠/١٠٠ × ٤١ر٨٦١/٣ × (٥٠ر٢ × ٥٠ر١) × ٣٦١ = ٣٨/٩٠٢ر٢ ر.س

I B- <u>BITUMINOUS WEARING COURSE CLASS "B" :</u>

اولا ب <u>طبقة السفلتة السطحية صنف "ب"</u>

1) <u>Gradation:</u>

Gradation was checked for samples taken from 24 different locations and was found to meet the job mix formula with specified tolerance limits except the following deficiencies :

١) <u>التدرج :</u>

تم فحص التدرج بالنسبة للعينات الماخوذة من ٢٤ موقعا مختلفا ووجد بانها تطابق معادلة خليط العمل مع الفرق المسموح به باستثناء النواقص التالية :

Station	3/4"	1/2"	No.4	10	40	80	200	Deficiency %
M-1					+2.5			12.5 %
B-2			-0.2					0.6 %
M-2			+0.2	+0.1				0.9 %

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الرقم .... التاريخ .... المرفقات ....

ملاحظة : يرجى في حالة الرد الاشارة الى الرقم والتاريخ واعادة صورة الخطاب المرافقة

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المملكة العربية السعودية

وزارة المواصلات

الموضوع :

Station	3/4"	1/2"	No.4	10	40	80	200	Deficiency %
B- 3			+4.0	+2.4				19.2 %
M- 3		+0.3	+0.2					1.5 %
B- 4				+1.1				3.3 %
B- 5				+0.2	+0.3		-0.1	2.6 %
M- 5		+4.2			+1.9			22.1 %
B- 6		-0.6						1.8 %
M- 6			+4.5	+2.6				21.3 %
B- 7					-2.1	-0.2		11.5 %
B-10					-1.8			9.0 %
M- 8					-0.6	-0.9		7.5 %
B-12	-0.8							2.4 %

الموقع	٣/٤	١/٢	رقم٤	١٠	٤٠	٨٠	٢٠٠	النقص%
م - ١					+٢ر٥			١٢ر٥ ٪
ب - ٢			-٢ر٠					٠ر٦ ٪
م - ٢			+٢ر٠	+١ر٠				٠ر٩ ٪
ب - ٣			+٤ر	+٢ر٤				١٩ر٢ ٪
م - ٣		+٠ر٣	+٠ر٢					١ر٥ ٪
بـ ٤				+١ر١				٣ر٣ ٪
ب - ٥				+٠ر٢	+٠ر٣		-٠ر١	٢ر٦ ٪
م - ٥ +٤ر٢					+١ر٩			٢٢ر١ ٪
بـ٦-٠ر٦								١ر٨ ٪
م- ٦			+٤ر٥	+٢ر٦				٢١ر٣ ٪
بـ٧					-٢ر١	-٠ر٢		١١ر٥ ٪
بـ١٠					-١ر٨			٩ر٠ ٪
م-٨					-٠ر٦	-٠ر٩		٧ر٥ ٪
بـ١٢ -٠ر٨								٢ر٤ ٪

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٦/يتبع

الرقم .... التاريخ .... المرفقات ....

ملاحظة : يرجى في حالة الرد الاشارة الى الرقم والتاريخ واعادة صورة الخطاب المرفقة

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المملكة العربية السعودية
وزارة المواصلات

الموضوع :

The deficiencies at B-2,M-2 M-3,B-4,B-5,B-6 and B-12 are very minor and will not effect the utility and durability of the project.The committee recommends to accept them without any deduction.

ان النواقص فى ب - ٢ ، م - ٢ م - ٣ ، ب - ٤ ، ب - ٥ ، ب - ٦ ، ب - ١٢ ثانوية جدا وسوف لن تؤثر على الاستفادة من المشروع وقوة تحمله ج توصى اللجنة بقبولها دون اى حسم .

The deficiencies at M-1,B-3, M-5,M-6,B-7,B-10 and M-8 are minor and will not effect the utility and durability of the project.The committee recommends to accept them with the following deductions:

ان النواقص فى العينات م - ١ ، ب - ٣ ، م - ٥ ، م - ٦ ب - ٧ ، ب - ١٠ ح م - ٨ ، ثانوية وسوف لن تؤثر على الاستفادة من المشروع وقوة تحمله وتوصى اللجنة بقبولها مع الحسميات التالية .

Deduction = Item % x Deficiency % x Length x Width x Thickness x Rate

الحسم = نسبة البند x نسبة النقص x الطول x العرض x السماكة x معدل السعر

M- 1 = 0.12 x 0.125 x 4954 x 15.90 x 0.06 x 361 = SR. 25,591.92
B- 3 = 0.12 x 0.192 x 4954 x 15.90 x 0.06 x 361 = SR. 39,309.19
M- 5 = 0.12 x 0.221 x 4955 x 15.90 x 0.06 x 361 = SR. 45,255.64
M- 6 = 0.12 x 0.213 x 4954 x 15.90 x 0.06 x 361 = SR. 43,608.63
B- 7 = 0.12 x 0.115 x 4955 x 15.90 x 0.06 x 361 = SR. 23,549.32
B-10 = 0.12 x 0.09 (vol: 306+306+306+306) x 361 = SR. 4,772.13
M- 8 = 0.12 x 0.075 x (vol: 1602+1208) x 361 = SR. 9,129,69

م - ١ = ٠ر١٢ × ٠ر١٢٥ × ٤٩٥٤ × ١٥ر٩٠ × ٠ر٠٦ × ٣٦١ = ٢٥ر٥٩١/٩٢ ر٠س
ب - ٣ = ٠ر١٢ × ٠ر١٩٢ × ٤٩٥٤ × ١٥ر٩٠ × ٠ر٠٦ × ٣٦١ = ٣٩ر٣٠٩/١٩ ر٠س
م - ٥ = ٠ر١٢ × ٠ر٢٢١ × ٤٩٥٥ × ١٥ر٩٠ × ٠ر٠٦ × ٣٦١ = ٤٥ر٢٥٥/٦٤ ر٠س
م - ٦ = ٠ر١٢ × ٠ر٢١٣ × ٤٩٥٤ × ١٥ر٩٠ × ٠ر٠٦ × ٣٦١ = ٤٣ر٦٠٨/٦٣ ر٠س
ب - ٧ = ٠ر١٢ × ٠ر١١٥ × ٤٩٥٥ × ١٥ر٩٠ × ٠ر٠٦ × ٣٦١ = ٢٣ر٥٤٩/٣٢ ر٠س
ب - ١٠ = ٠ر١٢ × ٠ر٠٩ (٣٠٦+٣٠٦+٣٠٦+٣٠٦) × ٣٦١ = ٤ر٧٧٢/١٣ ر٠س
م - ٨ = ٠ر١٢ × ٠ر٠٧٥ × (١٦٠٢+١٢٠٨) × ٣٦١ = ٩ر١٢٩/٦٩ ر٠س

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الرقم .... التاريخ .... المرفقات ....

ملاحظة : يرجى فى حالة الرد الاشارة الى الرقم والتاريخ واعادة صورة الخطاب المرافقة

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المملكة العربية السعودية
وزارة المواصلات

الموضوع :

2) Asphalt content :

Asphalt content was checked for samples from 24 locations and was found within the tolerance limits of the job mix formula at all locations except the following :

B-2 = -0.3% ; M-2 = +0.6% ; B-3 = +0.4%
B-4 = +0.1% ; B-5 = +0.1% ; M-5 = +0.3%
B-6 = +0.3% ; M-6 = +0.1% ; B-7 = +0.1%
M-7 = +0.2% ; B-8 = +0.1%

٢) نسبة الاسفلت :

تم فحص نسبة الاسفلت بالنسبة لعينات من ٢٤ موقعا وتبين بانها ضمن حدود الفرق المسموح به من معادلة خليط العمل فى جميع المواقع باستثناء ما يلى :

ب - ٢ = - ٣ر٠٪ ، م - ٢ = + ٦ر٠٪ ، ب - ٣ = + ٤ر٠٪
ب - ٤ = + ١ر٠٪ ، ب - ٥ = + ١ر٠٪ ، م - ٥ = + ٣ر٠٪
ب - ٦ = + ٣ر٠٪ ، م - ٦ = + ١ر٠٪ ، ب - ٧ = + ١ر٠٪
م - ٧ = + ٢ر٠٪ ، ب - ٨ = + ١ر٠٪

Deviation at B-2 is very minor and will not effect the utility and durability of the project. The committee recommends to accept this with following deduction :

كانت المخالفة عند العينة ب - ٢ ثانوية جدا وسوف لن تؤثر على الاستفادة من المشروع وقوة تحمله . توصى اللجنة بقبول هذا مع الحسم التالى :

Deduction = Item % x Deficiency % x Length x Width x Thickness x Rate

الحسم = نسبة البند x نسبة النقص x الطول x العرض x السماكة x معدل السعر

B-2 = 0.12 x 0.30 x 4955 x 15.90 x 0.06 x 361 = SR. 61,433.00

ب - ٢ = ١٢ر٠ x ٣٠ر٠ x ٤٩٥٥ x ٩٠ر١٥ x ٠٦ر٠ x ٣٦١ = ٦١٫٤٣٣/٠٠ ر.س

Deficiencies at all other sections referred above are very minor and are on positive side and the gradation is also found

بالنسبة للنواقص فى جميع الاجزاء الاخرى المشار اليها بعاليه ثانوية جدا وهى فى الجانب الايجابى كما وجد التدرج

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٨ / يتبع

الرقم .... التاريخ .... المرفقات ....

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الموضوع :

to be on finer side.Therefore there is no danger of bleeding. The committee recommends to accept the above deviation without any penalty.

فى الجانب الاكثر نعومة. لذلك لا يوجد خطر من النزف. توصى اللجنة بقبول المخالفة المذكورة بعاليه دون تطبيق اى حسم.

3) Compaction :

Compaction was checked by taking cores at 62 stations and was found equal to or more than the specified 96% at all locations except the following :

B- 6 = -1%	Sh-8 = -2%
Sh-9 = -1%	Sh-16= -5%
Sh-18= -3%	Sh-20= -2%
Sh-21= -1%	Sh-22= -2%
Sh-27= -1%	Sh-37= -3%

The deficiencies at B-6,Sh-9 Sh-21 and Sh-27 are very minor and will not effect the utility and durability of the project.The committee recommends to accept them without any deduction.Deficiencies at Sh-8, Sh-16,Sh-18,Sh-20,Sh-22 and Sh-37 are minor and will not effect the durability of the project.The committee recommends to accept them with the following deductions :

٣) الــدك :

تم فحص الدك باخذ عينات قالب من ٦٢ موقعا ووجدت فى جميع المواقع متساوية او تزيد عن نسبة ٩٦٪ المحددة باستثناء ما يلى :

ب - ٦ = - ١٪ ، كف - ٨ = - ٢٪ ،
كف - ٩ = - ١٪ ، كف - ١٦ = - ٥٪
كف - ١٨ = - ٣٪ ، كف - ٢٠ = - ٢٪
كف - ٢١ = - ١٪ ، كف - ٢٢ = - ٢٪
كف - ٢٧ = - ١٪ ، كف - ٣٧ = - ٣٪

تعتبر النواقص فى ب - ٦ ، كف - ٩ ، كف - ٢١ ، وكف - ٢٧ ، ثانوية جدا ولا تؤثر على الاستفادة من المشروع او قوة تحمله. توصى اللجنة بقبولها دون تطبيق اى حسميات.
النواقص فى كف - ٨ ، كف - ١٦ ، كف - ١٨ ، كف - ٢٠ ، كف - ٢٢ ، وكف - ٣٧ ، ثانوية ولا تؤثر على الاستفادة من المشروع او قوة تحمله. توصى اللجنة بقبولها مع تطبيق الحسميات التالية :

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بسم الله الرحمن الرحيم

المملكة العربية السعودية

وزارة المواصلات

الموضوع :

Deduction = Item % x Deficiency % x Length x Width x Thickness x Rate

الحسم = نسبة البند x نسبة النقص x الطول x العرض x السماكة x معدل السعر

Sh- 8 = 0.12 x 0.40 x 6606   x 4.50 x 0.06 x 361 = SR.30,906.57
Sh-16 = 0.12 x 0.99 x 575.44 x 4.00 x 0.06 x 361 = SR. 5,922.91
Sh-18 = 0.12 x 0.60 x 584.82 x 4.00 x 0.06 x 361 = SR. 3,648.15
Sh-20 = 0.12 x 0.40 x 345.74 x 4.00 x 0.06 x 361 = SR. 1,437.84
Sh-22 = 0.12 x 0.40 x 345.74 x 4.00 x 0.06 x 361 = SR. 1,437.84
Sh-37 = 0.12 x 0.60 x 2074.95x 4.50 x 0.06 x 361 = SR. 3,642.17

كف - ٨ = ٠ر١٢ x ٠ر٤٠ x ٦٦٠٦ x ٤ر٥٠ x ٠ر٠٦ x ٣٦١ = ٣٠ر٩٠٦/٥٧ ر.س
كف - ١٦ = ٠ر١٢ x ٠ر٩٩ x ٥٧٥ر٤٤ x ٤ر٠٠ x ٠ر٠٦ x ٣٦١ = ٥ر٩٢٢/٩١ ر.س
كف - ١٨ = ٠ر١٢ x ٠ر٦٠ x ٥٨٤ر٨٢ x ٤ر٠٠ x ٠ر٠٦ x ٣٦١ = ٣ر٦٤٨/١٥ ر.س
كف - ٢٠ = ٠ر١٢ x ٠ر٤٠ x ٣٤٥ر٧٤ x ٤ر٠٠ x ٠ر٠٦ x ٣٦١ = ١ر٤٣٧/٨٤ ر.س
كف - ٢٢ = ٠ر١٢ x ٠ر٤٠ x ٣٤٥ر٧٤ x ٤ر٠٠ x ٠ر٠٦ x ٣٦١ = ١ر٤٣٧/٨٤ ر.س
كف - ٣٧ = ٠ر١٢ x ٠ر٦٠ x ٢٠٧٤ر٩٥ x ٤ر٥٠ x ٠ر٠٦ x ٣٦١ = ٣ر٦٤٢/١٧ ر.س

4) Riding quality :

Riding quality of the bituminous wearing course is satisfactory in general except for sections of bridges at the joints. The deviations are very minor and the committee recommends to accept this with the following deductions :

٤) نوعية السير :

تعتبر نوعية السير على طبقة السفلتة السطحية للطريق مرضية بشكل عام باستثناء اجزاء الجسور عند الفواصل . تعتبر المخالفات ثانوية جدا . توصي اللجنة بقبول هذه مع تطبيق الحسميات التالية :

Deduction = Item % x Deficiency % x Length x Width x Thickness x Rate

الحسم = نسبة البند x نسبة النقص x الطول x العرض x السماكة x معدل السعر

1,4 & 7 = 0.12 x 0.30 x 210   x 2 x 24.70 x 0.06 x 361   = SR. 8,089.23
2 = 0.12 x 0.30 x 675.15x20.9 x 2 x 0.06 x 361   = SR.22,005.82
5 = 0.12 x 0.30 x 168   x12.8 x 0.06 x 361   = SR. 1,676.80
6 = 0.12 x 0.30 x 32.50 x(20.9+25.10)x 0.06 x 361   = SR. 1,165.74

cont/10

/١٠ يتبع

الرقم .... التاريخ .... المرفقات ....

ملاحظة : يرجى في حالة الرد الاشارة الى الرقم والتاريخ واعادة صورة الخطاب المرفقة

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Appendix D

* Descriptive Statistic Tables for Contractor's grades 1, 2, 3, and 4.

* Factor's (IIN) Tables for Contractor's grades 1, 2, 3,and 4.

* Correlation coefficient calculations for Spearman (rank tables, formulas used and calculation procedures).

* ANOVA SAS Computer output for factor No.1.

Table 1 - Descriptive Statistics of Research Data for Grade 1 Contractors.

	FACTOR	FREQUENCIES M.E 3	E 2	S.E 1	N.E 0	MEAN	STD	C.V %
1	Clarity of responsibilites and authority.	4	2	3	0	2.11	0.93	44.0
2	Qualification of the owner's inspection team.	6	3	0	0	2.67	0.50	18.8
3	Owners team familiarity with the construction process.	4	5	0	0	2.44	0.53	21.6
4	Assignment of QC responsibility to the consultant.	1	4	4	0	1.67	0.71	42.4
5	Qualification of contractors during bidding process.	3	4	2	0	2.11	0.78	37.0
6	Selection of the lowest bidder to construct the project.	4	2	0	3	1.78	1.39	78.4
7	Contractor's previous experience.	4	5	0	0	2.44	0.53	21.6
8	Contractor's financial status during construction.	4	4	1	0	2.33	0.71	30.3
9	Contractor's labor and equipment capability.	5	4	0	0	2.56	0.53	20.6
10	Amount of work sub-contracted.	0	1	8	0	1.11	0.33	30.0
11	Cost escalation of material, labor ...etc.	2	7	0	0	2.22	0.44	19.8
12	Financial incentives to produce higher quality level.	4	5	0	0	2.44	0.53	21.6
13	Delay in contractor progress payment.	1	7	1	0	2.00	0.50	25.0
14	Pavement not designed to the regional conditions.	8	1	0	0	2.89	0.33	11.5
15	Design errors from inaccurate assumptions, data...etc.	8	0	1	0	2.78	0.67	24.0
16	Insufficient owner involvment during design phase.	2	2	5	0	1.67	0.87	52.0
17	Accuracy of investigation on soil type.	2	7	0	0	2.22	0.44	19.8
18	Accuracy of data related to traffic volume,...etc.	6	3	0	0	2.67	0.50	18.8
19	Climate and its relation to materials used.	6	3	0	0	2.67	0.50	18.8
20	The use of full depth asphalt concrete cross-section.	2	7	0	0	2.22	0.44	19.8
21	Consistency of specification interpretation of aggregate quality.	7	2	0	0	2.78	0.44	15.9
22	Consistency of specification interpretation of asphalt quality.	4	4	1	0	2.33	0.71	30.3
23	Consistency of specification interpretation of mix composition.	6	2	1	0	2.56	0.73	28.4
24	Consistency of specification interpretation of compaction level.	7	2	0	0	2.78	0.44	15.9
25	Level of technical details to specify the desired product quality.	3	5	0	1	2.11	0.93	44.0
26	Over-specification of materials and equipment,...etc.	0	6	3	0	1.67	0.50	30.0
27	Limitation on material source selection, equipment type,...etc,	1	7	1	0	2.00	0.50	25.0
28	Mix design does not consider the local conditions.	7	1	1	0	2.67	0.71	26.5
29	Mix design method used locally.	2	5	1	1	1.89	0.93	49.1
30	The use of dense graded job mix formula for mixture productio	2	5	2	0	2.00	0.71	35.4
31	The use of open graded job mix formula for mixture production	1	7	1	0	2.00	0.50	25.0
32	Wide job mix formula tolerances.	1	6	2	0	1.89	0.60	31.8

Table 1 - Descriptive Statistics of Research Data for Grade 1 Contractors.

	FACTOR	FREQUENCIES				MEAN	STD	C.V %
		M.E	E	S.E	N.E			
		3	2	1	0			
33	Asphalt mixture properties (e.g. stability, durabilty,...ect.).	6	2	1	0	2.56	0.73	28.4
34	QC procedure performed by the owner team during constructior	6	3	0	0	2.67	0.50	18.8
35	Contractor's QC for material at mixing plant stockpiles.	3	2	4	0	1.89	0.93	49.1
36	Owner's evaluation of the contractor's material source.	1	3	4	1	1.44	0.88	61.1
37	Availability of the specified material quality.	7	2	0	0	2.78	0.44	15.9
38	Uniformity of material at source.	4	5	0	0	2.44	0.53	21.6
39	Aggregate crushing process at material source.	4	3	1	1	2.11	1.05	49.9
40	Aggregate quality (e.g. gradation, shape, type,...etc.).	6	3	0	0	2.67	0.50	18.8
41	Asphalt grade and quality.	4	4	1	0	2.33	0.71	30.3
42	Variation on aggregate gradation in stockpiles, mixing,...etc.	2	6	1	0	2.11	0.60	28.5
43	Variation on asphalt content during mixture production.	6	3	0	0	2.67	0.50	18.8
44	Amount of filler materials in the mixture.	6	2	0	1	2.44	1.01	41.5
45	Continuous changing in mix design.	3	3	2	1	1.89	1.05	55.8
46	The use of marginal material.	4	5	0	0	2.44	0.53	21.6
47	Monitoring mixing operations.	3	4	2	0	2.11	0.78	37.0
48	Lack of experienced staff on contractor and owner team.	7	2	0	0	2.78	0.44	15.9
49	Condition of road bed soil.	4	5	0	0	2.44	0.53	21.6
50	Uniformity of mixture placement and compaction operations.	4	4	1	0	2.33	0.71	30.3
51	Paver and roller mechanical condition and type.	5	4	0	0	2.56	0.53	20.6
52	Compacting pattern used to achieve the desired density.	3	4	2	0	2.11	0.78	37.0
53	Roller driver experience to observe mixture behavior.	5	3	1	0	2.44	0.73	29.7
54	Compacting at wrong time.	7	2	0	0	2.78	0.44	15.9
55	Over-compaction.	4	3	2	0	2.22	0.83	37.5
56	Evaluation practices used for product acceptance.	1	5	3	0	1.78	0.67	37.5
57	Qualifiction of the people performing acceptance procedures.	3	5	1	0	2.22	0.67	30.0
58	Amount of payment deduction for non-compliance product.	0	5	3	1	1.44	0.73	50.3
59	Fairness of the method adopted by the MOC for deduction.	1	6	2	0	1.89	0.60	31.8

Table 2 - Descriptive Statistics for Research Data for Grade 2 Contractors.

	Factor	FREQUENCIES M.E 3	E 2	S.E 1	N.E 0	MEAN	STD	C.V%
1	Clarity of responsibilites and authority.	4	1	0	0	2.80	0.45	16.0
2	Qualification of the owner's inspection team.	3	1	1	0	2.40	0.89	37.3
3	Owners team familiarity with the construction process.	3	1	1	0	2.40	0.89	37.3
4	Assignment of QC responsibility to the consultant.	3	1	1	0	2.40	0.89	37.3
5	Qualification of contractors during bidding process.	1	2	2	0	1.80	0.84	46.5
6	Selection of the lowest bidder to construct the project.	1	0	3	1	1.20	1.10	91.3
7	Contractor's previous experience.	1	4	0	0	2.20	0.45	20.3
8	Contractor's financial status during construction.	2	2	0	1	2.00	1.22	61.2
9	Contractor's labor and equipment capability.	1	2	2	0	1.80	0.84	46.5
10	Amount of work sub-contracted.	0	1	2	2	0.80	0.84	104.6
11	Cost escalation of material, labor ...etc.	1	0	4	0	1.40	0.89	63.9
12	Financial incentives to produce higher quality level.	1	3	1	0	2.00	0.71	35.4
13	Delay in contractor progress payment.	0	4	1	0	1.80	0.45	24.8
14	Pavement not designed to the regional conditions.	5	0	0	0	3.00	0.00	0.0
15	Design errors from inaccurate assumptions, data...etc.	4	0	1	0	2.60	0.89	34.4
16	Insufficient owner involvment during design phase.	0	2	2	1	1.20	0.84	69.7
17	Accuracy of investigation on soil type.	3	2	0	0	2.60	0.55	21.1
18	Accuracy of data related to traffic volume,...etc.	3	2	0	0	2.60	0.55	21.1
19	Climate and its relation to materials used.	5	0	0	0	3.00	0.00	0.0
20	The use of full depth asphalt concrete cross-section.	3	1	1	0	2.40	0.89	37.3
21	Consistency of specification interpretation of aggregate quality.	5	0	0	0	3.00	0.00	0.0
22	Consistency of specification interpretation of asphalt quality.	4	0	1	0	2.60	0.89	34.4
23	Consistency of specification interpretation of mix composition.	4	0	1	0	2.60	0.89	34.4
24	Consistency of specification interpretation of compaction level.	3	1	1	0	2.40	0.89	37.3
25	Level of technical details required to specify the desired quality.	0	4	0	1	1.60	0.89	55.9
26	Over-specification of materials and equipment,...etc.	0	3	2	0	1.60	0.55	34.2
27	Limitation on material source selection, equipment type,...etc,	1	3	1	0	2.00	0.71	35.4
28	Mix design does not consider the local conditions.	4	1	0	0	2.80	0.45	16.0
29	Mix design method used locally.	3	2	0	0	2.60	0.55	21.1
30	The use of dense graded job mix formula for mixture production.	2	2	1	0	2.20	0.84	38.0
31	The use of open graded job mix formula for mixture production.	2	2	1	0	2.20	0.84	38.0
32	Wide job mix formula tolerances.	2	2	1	0	2.20	0.84	38.0
33	Asphalt mixture properties (e.g. stability, durabilty,...ect.).	4	1	0	0	2.80	0.45	16.0
34	QC procedure performed by the owner team during construction.	3	1	1	0	2.40	0.89	37.3
35	Contractor's QC for material at mixing plant stockpiles.	2	3	0	0	2.40	0.55	22.8
36	Owner's evaluation of the contractor's material source.	2	3	0	0	2.40	0.55	22.8

Table 2 - Descriptive Statistics for Research Data for Grade 2 Contractors.

	Factor	FREQUENCIES M.E 3	E 2	S.E 1	N.E 0	MEAN	STD	C.V%
37	Availability of the specified material quality.	4	1	0	0	2.80	0.45	16.0
38	Uniformity of material at source.	3	2	0	0	2.60	0.55	21.1
39	Aggregate crushing process at material source.	3	1	0	1	2.20	1.30	59.3
40	Aggregate quality (e.g. gradation, shape, type,...etc.).	5	0	0	0	3.00	0.00	0.0
41	Asphalt grade and quality.	4	1	0	0	2.80	0.45	16.0
42	Variation on aggregate gradation in stockpiles, mixing,...etc.	1	3	1	0	2.00	0.71	35.4
43	Variation on asphalt content during mixture production.	2	2	1	0	2.20	0.84	38.0
44	Amount of filler materials in the mixture.	5	0	0	0	3.00	0.00	0.0
45	Continuous changing in mix design.	2	2	0	1	2.00	1.22	61.2
46	The use of marginal material.	4	1	0	0	2.80	0.45	16.0
47	Monitoring mixing operations.	2	2	1	0	2.20	0.84	38.0
48	Lack of experienced staff on contractor and owner team.	2	3	0	0	2.40	0.55	22.8
49	Condition of road bed soil.	3	2	0	0	2.60	0.55	21.1
50	Uniformity of mixture placement and compaction operations.	2	2	1	0	2.20	0.84	38.0
51	Paver and roller mechanical condition and type.	1	3	1	0	2.00	0.71	35.4
52	Compacting pattern used to achieve the desired density.	1	3	1	0	2.00	0.71	35.4
53	Roller driver experience to observe mixture behavior.	2	2	1	0	2.20	0.84	38.0
54	Compacting at wrong time.	2	2	1	0	2.20	0.84	38.0
55	Over-compaction.	2	2	1	0	2.20	0.84	38.0
56	Evaluation practices used for product acceptance.	0	4	1	0	1.80	0.45	24.8
57	Qualifiction of the people performing acceptance procedures.	3	2	0	0	2.60	0.55	21.1
58	Amount of payment deduction for non-compliance product.	0	4	1	0	1.80	0.45	24.8
59	Fairness of the method adopted by the MOC for deduction.	0	4	1	0	1.80	0.45	24.8

Table 3 - Descriptive Statistics for Research Data for Grade 3 Contractors.

		FREQUENCIES						
		M.E	E	S.E	N.E			
	FACTOR	3	2	1	0	MEAN	STD	C.V%
1	Clarity of responsibilites and authority.	10	1	1	0	2.75	0.62	22.6
2	Qualification of the owner's inspection team.	7	4	1	0	2.50	0.67	27.0
3	Owners team familiarity with the construction process.	8	1	3	0	2.42	0.90	37.3
4	Assignment of QC responsibility to the consultant.	4	4	1	3	1.75	1.22	69.5
5	Qualification of contractors during bidding process.	6	4	2	0	2.33	0.78	33.4
6	Selection of the lowest bidder to construct the project.	6	4	2	0	2.33	0.78	33.4
7	Contractor's previous experience.	6	6	0	0	2.50	0.52	20.9
8	Contractor's financial status during construction.	5	5	1	1	2.17	0.94	43.3
9	Contractor's labor and equipment capability.	9	1	2	0	2.58	0.79	30.7
10	Amount of work sub-contracted.	0	6	3	3	1.25	0.87	69.3
11	Cost escalation of material, labor ...etc.	5	4	3	0	2.17	0.83	38.5
12	Financial incentives to produce higher quality level.	2	4	6	0	1.67	0.78	46.7
13	Delay in contractor progress payment.	6	2	4	0	2.17	0.94	43.3
14	Pavement not designed to the regional conditions.	9	2	1	0	2.67	0.65	24.4
15	Design errors from inaccurate assumptions, data...etc.	8	3	1	0	2.58	0.67	25.9
16	Insufficient owner involvment during design phase.	4	5	1	2	1.92	1.08	56.5
17	Accuracy of investigation on soil type.	7	5	0	0	2.58	0.51	19.9
18	Accuracy of data related to traffic volume,...etc.	6	3	3	0	2.25	0.87	38.5
19	Climate and its relation to materials used.	8	3	1	0	2.58	0.67	25.9
20	The use of full depth asphalt concrete cross-section.	5	3	1	3	1.83	1.27	69.1
21	Consistency of specification interpretation of aggregate quality.	10	2	0	0	2.83	0.39	13.7
22	Consistency of specification interpretation of asphalt quality.	9	2	1	0	2.67	0.65	24.4
23	Consistency of specification interpretation of mix composition.	9	2	1	0	2.67	0.65	24.4
24	Consistency of specification interpretation of compaction level.	7	4	1	0	2.50	0.67	27.0
25	Level of technical details required to specify the desired quality.	6	3	1	2	2.08	1.16	55.9
26	Over-specification of materials and equipment,...etc.	1	5	4	2	1.42	0.90	63.6
27	Limitation on material source selection, equipment type,...etc,	4	3	5	0	1.92	0.90	47.0
28	Mix design does not consider the local conditions.	7	5	0	0	2.58	0.51	19.9
29	Mix design method used locally.	9	3	0	0	2.75	0.45	16.4
30	The use of dense graded job mix formula for mixture production.	6	4	1	1	2.25	0.97	42.9
31	The use of open graded job mix formula for mixture production.	8	3	1	0	2.58	0.67	25.9
32	Wide job mix formula tolerances.	8	2	1	1	2.42	1.00	41.2

Table 3 - Descriptive Statistics for Research Data for Grade 3 Contractors.

	FACTOR	FREQUENCIES				MEAN	STD	C.V%
		M.E	E	S.E	N.E			
		3	2	1	0			
33	Asphalt mixture properties (e.g. stability, durabilty,...ect.).	9	1	0	2	2.42	1.16	48.2
34	QC procedure performed by the owner team during construction.	10	0	2	0	2.67	0.78	29.2
35	Contractor's QC for material at mixing plant stockpiles.	6	3	3	0	2.25	0.87	38.5
36	Owner's evaluation of the contractor's material source.	7	3	1	1	2.33	0.98	42.2
37	Availability of the specified material quality.	9	2	1	0	2.67	0.65	24.4
38	Uniformity of material at source.	8	3	1	0	2.58	0.67	25.9
39	Aggregate crushing process at material source.	8	1	2	1	2.33	1.07	46.0
40	Aggregate quality (e.g. gradation, shape, type,...etc.).	10	1	1	0	2.75	0.62	22.6
41	Asphalt grade and quality.	7	4	0	1	2.42	0.90	37.3
42	Variation on aggregate gradation in stockpiles, mixing,...etc.	7	1	3	1	2.17	1.11	51.4
43	Variation on asphalt content during mixture production.	7	2	2	1	2.25	1.06	46.9
44	Amount of filler materials in the mixture.	11	1	0	0	2.92	0.29	9.9
45	Continuous changing in mix design.	8	2	1	1	2.42	1.00	41.2
46	The use of marginal material.	8	4	0	0	2.67	0.49	18.5
47	Monitoring mixing operations.	7	5	0	0	2.58	0.51	19.9
48	Lack of experienced staff on contractor and owner team.	7	4	1	0	2.50	0.67	27.0
49	Condition of road bed soil.	9	3	0	0	2.75	0.45	16.4
50	Uniformity of mixture placement and compaction operations.	8	3	1	0	2.58	0.67	25.9
51	Paver and roller mechanical condition and type.	5	6	1	0	2.33	0.65	27.9
52	Compacting pattern used to achieve the desired density.	5	6	1	0	2.33	0.65	27.9
53	Roller driver experience to observe mixture behavior.	6	3	3	0	2.25	0.87	38.5
54	Compacting at wrong time.	9	2	1	0	2.67	0.65	24.4
55	Over-compaction.	7	2	3	0	2.33	0.89	38.0
56	Evaluation practices used for product acceptance.	5	3	3	1	2.00	1.04	52.2
57	Qualifiction of the people performing acceptance procedures.	8	2	1	1	2.42	1.00	41.2
58	Amount of payment deduction for non-compliance product.	4	2	1	5	1.42	1.38	97.3
59	Fairness of the method adopted by the MOC for deduction.	4	2	3	3	1.58	1.24	78.3

Table 4 - Descriptive Statistics of Research Data for Grade 4 Contractors.

	Factor	FREQUENCIES M.E 3	E 2	S.E 1	N.E 0	MEAN	STD	C.V%
1	Clarity of responsibilites and authority.	3	2	0	0	2.60	0.55	21.1
2	Qualification of the owner's inspection team.	3	2	0	0	2.60	0.55	21.1
3	Owners team familiarity with the construction process.	4	1	0	0	2.80	0.45	16.0
4	Assignment of QC responsibility to the consultant.	2	3	0	0	2.40	0.55	22.8
5	Qualification of contractors during bidding process.	2	3	0	0	2.40	0.55	22.8
6	Selection of the lowest bidder to construct the project.	2	2	1	0	2.20	0.84	38.0
7	Contractor's previous experience.	4	1	0	0	2.80	0.45	16.0
8	Contractor's financial status during construction.	2	3	0	0	2.40	0.55	22.8
9	Contractor's labor and equipment capability.	4	1	0	0	2.80	0.45	16.0
10	Amount of work sub-contracted.	0	2	3	0	1.40	0.55	39.1
11	Cost escalation of material, labor ...etc.	2	3	0	0	2.40	0.55	22.8
12	Financial incentives to produce higher quality level.	1	2	1	1	1.60	1.14	71.3
13	Delay in contractor progress payment.	4	1	0	0	2.80	0.45	16.0
14	Pavement not designed to the regional conditions.	4	1	0	0	2.80	0.45	16.0
15	Design errors from inaccurate assumptions, data...etc.	4	1	0	0	2.80	0.45	16.0
16	Insufficient owner involvment during design phase.	4	1	0	0	2.80	0.45	16.0
17	Accuracy of investigation on soil type.	4	1	0	0	2.80	0.45	16.0
18	Accuracy of data related to traffic volume,...etc.	2	3	0	0	2.40	0.55	22.8
19	Climate and its relation to materials used.	3	1	0	1	2.20	1.30	59.3
20	The use of full depth asphalt concrete cross-section.	2	3	0	0	2.40	0.55	22.8
21	Consistency of specification interpretation of aggregate quality.	3	2	0	0	2.60	0.55	21.1
22	Consistency of specification interpretation of asphalt quality.	2	3	0	0	2.40	0.55	22.8
23	Consistency of specification interpretation of mix composition.	3	2	0	0	2.60	0.55	21.1
24	Consistency of specification interpretation of compaction level.	3	2	0	0	2.60	0.55	21.1
25	Level of technical details required to specify the desired quality.	3	2	0	0	2.60	0.55	21.1
26	Over-specification of materials and equipment,...etc.	2	2	1	0	2.20	0.84	38.0
27	Limitation on material source selection, equipment type,...etc,	1	1	2	1	1.40	1.14	81.4
28	Mix design does not consider the local conditions.	4	1	0	0	2.80	0.45	16.0
29	Mix design method used locally.	2	2	0	1	2.00	1.22	61.2
30	The use of dense graded job mix formula for mixture production.	3	2	0	0	2.60	0.55	21.1
31	The use of open graded job mix formula for mixture production.	2	3	0	0	2.40	0.55	22.8
32	Wide job mix formula tolerances.	1	3	1	0	2.00	0.71	35.4

Table 4 - Descriptive Statistics of Research Data for Grade 4 Contractors.

	Factor	FREQUENCIES M.E 3	E 2	S.E 1	N.E 0	MEAN	STD	C.V%
33	Asphalt mixture properties (e.g. stability, durabilty,...ect.).	4	1	0	0	2.80	0.45	16.0
34	QC procedure performed by the owner team during construction.	2	3	0	0	2.40	0.55	22.8
35	Contractor's QC for material at mixing plant stockpiles.	2	2	1	0	2.20	0.84	38.0
36	Owner's evaluation of the contractor's material source.	1	2	2	0	1.80	0.84	46.5
37	Availability of the specified material quality.	4	1	0	0	2.80	0.45	16.0
38	Uniformity of material at source.	3	2	0	0	2.60	0.55	21.1
39	Aggregate crushing process at material source.	2	3	0	0	2.40	0.55	22.8
40	Aggregate quality (e.g. gradation, shape, type,...etc.).	5	0	0	0	3.00	0.00	0.0
41	Asphalt grade and quality.	2	3	0	0	2.40	0.55	22.8
42	Variation on aggregate gradation in stockpiles, mixing,...etc.	3	2	0	0	2.60	0.55	21.1
43	Variation on asphalt content during mixture production.	1	3	1	0	2.00	0.71	35.4
44	Amount of filler materials in the mixture.	3	2	0	0	2.60	0.55	21.1
45	Continuous changing in mix design.	0	2	1	2	1.00	1.00	100.0
46	The use of marginal material.	3	2	0	0	2.60	0.55	21.1
47	Monitoring mixing operations.	3	2	0	0	2.60	0.55	21.1
48	Lack of experienced staff on contractor and owner team.	5	0	0	0	3.00	0.00	0.0
49	Condition of road bed soil.	3	2	0	0	2.60	0.55	21.1
50	Uniformity of mixture placement and compaction operations.	3	2	0	0	2.60	0.55	21.1
51	Paver and roller mechanical condition and type.	2	3	0	0	2.40	0.55	22.8
52	Compacting pattern used to achieve the desired density.	2	2	1	0	2.20	0.84	38.0
53	Roller driver experience to observe mixture behavior.	2	3	0	0	2.40	0.55	22.8
54	Compacting at wrong time.	4	1	0	0	2.80	0.45	16.0
55	Over-compaction.	1	4	0	0	2.20	0.45	20.3
56	Evaluation practices used for product acceptance.	1	2	2	0	1.80	0.84	46.5
57	Qualifiction of the people performing acceptance procedures.	3	2	0	0	2.60	0.55	21.1
58	Amount of payment deduction for non-compliance product.	2	1	1	1	1.80	1.30	72.4
59	Fairness of the method adopted by the MOC for deduction.	1	2	0	2	1.40	1.34	95.8

Table 5 - Factor's Effect Index for Grade 1 Contractors

	FACTOR	Effect INDEX
31	Cost escalation of material, labor ...etc.	74.07%
32	Accuracy of investigation on soil type.	74.07%
33	The use of full depth asphalt concrete cross-section.	74.07%
34	Over-compaction.	74.07%
35	Qualifiction of the people performing acceptance procedures.	74.07%
36	Clarity of responsibilites and authority.	70.37%
37	Qualification of contractors during bidding process.	70.37%
38	Level of technical details required to specify the desired product quality.	70.37%
39	Aggregate crushing process at material source.	70.37%
40	Variation on aggregate gradation in stockpiles, mixing,...etc.	70.37%
41	Monitoring mixing operations.	70.37%
42	Compacting pattern used to achieve the desired pavement density.	70.37%
43	Delay in contractor progress payment.	66.67%
44	Limitation on material source selection, equipment type,...etc,	66.67%
45	The use of dense graded job mix formula for mixture production.	66.67%
46	The use of open graded job mix formula for mixture production.	66.67%
47	Mix design method used locally.	62.96%
48	Wide job mix formula tolerances.	62.96%
49	Contractor's QC for material at mixing plant stockpiles.	62.96%
50	Continuous changing in mix design.	62.96%
51	Fairness of the method adopted by the MOC for deduction calculations.	62.96%
52	Selection of the lowest bidder to construct the project.	59.26%
53	Evaluation practices used for product acceptance.	59.26%
54	Assignment of QC responsibility to the consultant.	55.56%
55	Insufficient owner involvment during design phase.	55.56%
56	Over-specification of materials and equipment,...etc.	55.56%
57	Owner's evaluation of the contractor's material source.	48.15%
58	Amount of payment deduction for non-compliance product.	48.15%
59	Amount of work sub-contracted.	37.04%

Table 5 - Factor's Effect Index for Grade 1 Contractors

	FACTOR	Effect INDEX
1	Pavement not designed to the regional conditions..	96.30%
2	Design errors from inaccurate assumptions, data...etc.	92.59%
3	Consistency of specification interpretation of aggregate quality & gradation.	92.59%
4	Consistency of specification interpretation of compaction level.	92.59%
5	Availability of the specified material quality (e.g. aggregate asphalt).	92.59%
6	Lack of experienced staff on contractor and owner team.	92.59%
7	Compacting at wrong time.	92.59%
8	Qualification of the owner's inspection team.	88.89%
9	Accuracy of data related to traffic volume,...etc.	88.89%
10	Climate and its relation to materials used.	88.89%
11	Mix design does not consider the local conditions.	88.89%
12	QC procedure performed by the owner team during construction.	88.89%
13	Aggregate quality (e.g. gradation, shape, type,...etc.).	88.89%
14	Variation on asphalt content during mixture production.	88.89%
15	Contractor's labor and equipment capability.	85.19%
16	Consistency of specification interpretation of mixture composition.	85.19%
17	Asphalt mixture properties (e.g. stability, durabilty,...ect.).	85.19%
18	Paver and roller mechanical condition and type.	85.19%
19	Owners team familiarity with the construction process.	81.48%
20	Contractor's previous experience.	81.48%
21	Financial incentives to produce higher quality level.	81.48%
22	Uniformity of material at source (ie. Aggregate gradation - asphalt grade).	81.48%
23	Amount of filler materials in the mixture.	81.48%
24	The use of marginal material.	81.48%
25	Condition of road bed soil.	81.48%
26	Roller driver experience to observe mixture behavior under roller.	81.48%
27	Contractor's financial status during construction.	77.78%
28	Consistency of specification interpretation of asphalt quality & content.	77.78%
29	Asphalt grade and quality.	77.78%
30	Uniformity of mixture placement and compaction operations.	77.78%

Table 6- Effect Index - Contractor's Grade 2

	FACTOR	Effect Index
1	Pavement not designed to the regional conditions.	100.00%
2	Design errors from inaccurate assumptions, data...etc.	100.00%
3	Consistency of specification interpretation of aggregate quality & gradation	100.00%
4	Consistency of specification interpretation of compaction level.	100.00%
5	Availability of the specified material quality (e.g. aggregate asphalt).	100.00%
6	Lack of experienced staff on contractor and owner team.	93.33%
7	Compacting at wrong time.	93.33%
8	Qualification of the owner's inspection team.	93.33%
9	Accuracy of data related to traffic volume,...etc.	93.33%
10	Climate and its relation to materials used.	93.33%
11	Mix design does not consider the local conditions.	93.33%
12	QC procedure performed by the owner team during construction.	86.67%
13	Aggregate quality (e.g. gradation, shape, type,...etc.).	86.67%
14	Variation on asphalt content during mixture production.	86.67%
15	Contractor's labor and equipment capability.	86.67%
16	Consistency of specification interpretation of mixture composition.	86.67%
17	Asphalt mixture properties (e.g. stability, durabilty,...ect.).	86.67%
18	Paver and roller mechanical condition and type.	86.67%
19	Owners team familiarity with the construction process.	86.67%
20	Contractor's previous experience.	86.67%
21	Financial incentives to produce higher quality level.	80.00%
22	Uniformity of material at source (ie. Aggregate gradation - asphalt grade).	80.00%
23	Amount of filler materials in the mixture.	80.00%
24	The use of marginal material.	80.00%
25	Condition of road bed soil.	80.00%
26	Roller driver experience to observe mixture behavior under roller.	80.00%
27	Contractor's financial status during construction.	80.00%
28	Consistency of specification interpretation of asphalt quality & content.	80.00%
29	Asphalt grade and quality.	80.00%
30	Uniformity of mixture placement and compaction operations.	73.33%
31	Cost escalation of material, labor ...etc.	73.33%

Table 6- Effect Index - Contractor's Grade 2

	FACTOR	Effect Index
32	Accuracy of investigation on soil type.	73.33%
33	The use of full depth asphalt concrete cross-section.	73.33%
34	Over-compaction.	73.33%
35	Qualifiction of the people performing acceptance procedures.	73.33%
36	Clarity of responsibilites and authority.	73.33%
37	Qualification of contractors during bidding process.	73.33%
38	Level of technical details required to specify the desired product quality.	73.33%
39	Aggregate crushing process at material source.	73.33%
40	Variation on aggregate gradation in stockpiles, mixing,...etc.	73.33%
41	Monitoring mixing operations.	66.67%
42	Compacting pattern used to achieve the desired pavement density.	66.67%
43	Delay in contractor progress payment.	66.67%
44	Limitation on material source selection, equipment type,...etc,	66.67%
45	The use of dense graded job mix formula for mixture production.	66.67%
46	The use of open graded job mix formula for mixture production.	66.67%
47	Mix design method used locally.	66.67%
48	Wide job mix formula tolerances.	60.00%
49	Contractor's QC for material at mixing plant stockpiles.	60.00%
50	Continuous changing in mix design.	60.00%
51	Fairness of the method adopted by the MOC for deduction calculations.	60.00%
52	Selection of the lowest bidder to construct the project.	60.00%
53	Evaluation practices used for product acceptance.	60.00%
54	Assignment of QC responsibility to the consultant.	53.33%
55	Insufficient owner involvment during design phase.	53.33%
56	Over-specification of materials and equipment,...etc.	46.67%
57	Owner's evaluation of the contractor's material source.	40.00%
58	Amount of payment deduction for non-compliance product.	40.00%
59	Amount of work sub-contracted.	26.67%

Table 7 - Factor's Effect Index for Grade 3 Contractors.

	FACTOR	Effect INDEX
1	Amount of filler materials in the mixture.	97.22%
2	Consistency of specification interpretation of aggregate quality.	94.44%
3	Clarity of responsibilites and authority.	91.67%
4	Mix design method used locally.	91.67%
5	Aggregate quality (e.g. gradation, shape, type,...etc.).	91.67%
6	Condition of road bed soil.	91.67%
7	Pavement not designed to the regional conditions.	88.89%
8	Consistency of specification interpretation of asphalt quality.	88.89%
9	Consistency of specification interpretation of mix composition.	88.89%
10	QC procedure performed by the owner team during construction.	88.89%
11	Availability of the specified material quality.	88.89%
12	The use of marginal material.	88.89%
13	Compacting at wrong time.	88.89%
14	Contractor's labor and equipment capability.	86.11%
15	Design errors from inaccurate assumptions, data...etc.	86.11%
16	Accuracy of investigation on soil type.	86.11%
17	Climate and its relation to materials used.	86.11%
18	Mix design does not consider the local conditions.	86.11%
19	The use of open graded job mix formula for mixture production.	86.11%
20	Uniformity of material at source.	86.11%
21	Monitoring mixing operations.	86.11%
22	Uniformity of mixture placement and compaction operations.	86.11%
23	Qualification of the owner's inspection team.	83.33%
24	Contractor's previous experience.	83.33%
25	Consistency of specification interpretation of compaction level.	83.33%
26	Lack of experienced staff on contractor and owner team.	83.33%
27	Owners team familiarity with the construction process.	80.56%
28	Wide job mix formula tolerances.	80.56%
29	Asphalt mixture properties (e.g. stability, durabilty,...ect.).	80.56%
30	Asphalt grade and quality.	80.56%
31	Continuous changing in mix design.	80.56%
32	Qualifiction of the people performing acceptance procedures.	80.56%
33	Qualification of contractors during bidding process.	77.78%

Table 7 - Factor's Effect Index for Grade 3 Contractors.

	FACTOR	Effect INDEX
34	Selection of the lowest bidder to construct the project.	77.78%
35	Owner's evaluation of the contractor's material source.	77.78%
36	Aggregate crushing process at material source.	77.78%
37	Paver and roller mechanical condition and type.	77.78%
38	Compacting pattern used to achieve the desired density.	77.78%
39	Over-compaction.	77.78%
40	Accuracy of data related to traffic volume,...etc.	75.00%
41	The use of dense graded job mix formula for mixture production.	75.00%
42	Contractor's QC for material at mixing plant stockpiles.	75.00%
43	Variation on asphalt content during mixture production.	75.00%
44	Roller driver experience to observe mixture behavior.	75.00%
45	Contractor's financial status during construction.	72.22%
46	Cost escalation of material, labor ...etc.	72.22%
47	Delay in contractor progress payment.	72.22%
48	Variation on aggregate gradation in stockpiles, mixing,...etc.	72.22%
49	Level of technical details required to specify the desired quality.	69.44%
50	Evaluation practices used for product acceptance.	66.67%
51	Insufficient owner involvment during design phase.	63.89%
52	Limitation on material source selection, equipment type,...etc,	63.89%
53	The use of full depth asphalt concrete cross-section.	61.11%
54	Assignment of QC responsibility to the consultant.	58.33%
55	Financial incentives to produce higher quality level.	55.56%
56	Fairness of the method adopted by the MOC for deduction.	52.78%
57	Over-specification of materials and equipment,...etc.	47.22%
58	Amount of payment deduction for non-compliance product.	47.22%
59	Amount of work sub-contracted.	41.67%

Table 8- Factor's Effect Index for Grade 4 Contractors.

	Factor	Effect INDEX
1	Aggregate quality (e.g. gradation, shape, type,...etc.).	100.00%
2	Lack of experienced staff on contractor and owner team.	100.00%
3	Owners team familiarity with the construction process.	93.33%
4	Contractor's previous experience.	93.33%
5	Contractor's labor and equipment capability.	93.33%
6	Delay in contractor progress payment.	93.33%
7	Pavement not designed to the regional conditions.	93.33%
8	Design errors from inaccurate assumptions, data...etc.	93.33%
9	Insufficient owner involvment during design phase.	93.33%
10	Accuracy of investigation on soil type.	93.33%
11	Mix design does not consider the local conditions.	93.33%
12	Asphalt mixture properties (e.g. stability, durabilty,...ect.).	93.33%
13	Availability of the specified material quality.	93.33%
14	Compacting at wrong time.	93.33%
15	Clarity of responsibilites and authority.	86.67%
16	Qualification of the owner's inspection team.	86.67%
17	Consistency of specification interpretation of aggregate quality.	86.67%
18	Consistency of specification interpretation of mix composition.	86.67%
19	Consistency of specification interpretation of compaction level.	86.67%
20	Level of technical details required to specify the desired quality.	86.67%
21	The use of dense graded job mix formula for mixture production.	86.67%
22	Uniformity of material at source.	86.67%
23	Variation on aggregate gradation in stockpiles, mixing,...etc.	86.67%
24	Amount of filler materials in the mixture.	86.67%
25	The use of marginal material.	86.67%
26	Monitoring mixing operations.	86.67%
27	Condition of road bed soil.	86.67%
28	Uniformity of mixture placement and compaction operations.	86.67%
29	Qualifiction of the people performing acceptance procedures.	86.67%
30	Assignment of QC responsibility to the consultant.	80.00%
31	Qualification of contractors during bidding process.	80.00%
32	Contractor's financial status during construction.	80.00%
33	Cost escalation of material, labor ...etc.	80.00%

Table 8- Factor's Effect Index for Grade 4 Contractors.

	Factor	Effect INDEX
34	Accuracy of data related to traffic volume,...etc.	80.00%
35	The use of full depth asphalt concrete cross-section.	80.00%
36	Consistency of specification interpretation of asphalt quality.	80.00%
37	The use of open graded job mix formula for mixture production.	80.00%
38	QC procedure performed by the owner team during construction.	80.00%
39	Aggregate crushing process at material source.	80.00%
40	Asphalt grade and quality.	80.00%
41	Paver and roller mechanical condition and type.	80.00%
42	Roller driver experience to observe mixture behavior.	80.00%
43	Selection of the lowest bidder to construct the project.	73.33%
44	Climate and its relation to materials used.	73.33%
45	Over-specification of materials and equipment,...etc.	73.33%
46	Contractor's QC for material at mixing plant stockpiles.	73.33%
47	Compacting pattern used to achieve the desired density.	73.33%
48	Over-compaction.	73.33%
49	Mix design method used locally.	66.67%
50	Wide job mix formula tolerances.	66.67%
51	Variation on asphalt content during mixture production.	66.67%
52	Owner's evaluation of the contractor's material source.	60.00%
53	Evaluation practices used for product acceptance.	60.00%
54	Amount of payment deduction for non-compliance product.	60.00%
55	Financial incentives to produce higher quality level.	53.33%
56	Amount of work sub-contracted.	46.67%
57	Limitation on material source selection, equipment type,...etc,	46.67%
58	Fairness of the method adopted by the MOC for deduction.	46.67%
59	Continuous changing in mix design.	33.33%

Table 9 - Factor Ranking for Grade 1 Contractors.

	FACTOR	RANK
1	Pavement not designed to the regional conditions.	1
2	Design errors from inaccurate assumptions, data...etc.	4.5
3	Consistency of specification interpretation of aggregate quality & gradation.	4.5
4	Consistency of specification interpretation of compaction level.	4.5
5	Availability of the specified material quality (e.g. aggregate asphalt).	4.5
6	Lack of experienced staff on contractor and owner team.	4.5
7	Compacting at wrong time.	4.5
8	Qualification of the owner's inspection team.	11
9	Accuracy of data related to traffic volume,...etc.	11
10	Climate and its relation to materials used.	11
11	Mix design does not consider the local conditions.	11
12	QC procedure performed by the owner team during construction.	11
13	Aggregate quality (e.g. gradation, shape, type,...etc.).	11
14	Variation on asphalt content during mixture production.	11
15	Contractor's labor and equipment capability.	16.5
16	Consistency of specification interpretation of mixture composition.	16.5
17	Asphalt mixture properties (e.g. stability, durabilty,...ect.).	16.5
18	Paver and roller mechanical condition and type.	16.5
19	Owners team familiarity with the construction process.	22.5
20	Contractor's previous experience.	22.5
21	Financial incentives to produce higher quality level.	22.5
22	Uniformity of material at source (ie. Aggregate gradation - asphalt grade).	22.5
23	Amount of filler materials in the mixture.	22.5
24	The use of marginal material.	22.5
25	Condition of road bed soil.	22.5
26	Roller driver experience to observe mixture behavior under roller.	22.5
27	Contractor's financial status during construction.	28.5
28	Consistency of specification interpretation of asphalt quality & content.	28.5
29	Asphalt grade and quality.	28.5
30	Uniformity of mixture placement and compaction operations.	28.5
31	Cost escalation of material, labor ...etc.	33
32	Accuracy of investigation on soil type.	33
33	The use of full depth asphalt concrete cross-section.	33

Table 9 - Factor Ranking for Grade 1 Contractors.

	FACTOR	RANK
34	Over-compaction.	33
35	Qualifiction of the people performing acceptance procedures.	33
36	Clarity of responsibilites and authority.	39
37	Qualification of contractors during bidding process.	39
38	Level of technical details required to specify the desired product quality.	39
39	Aggregate crushing process at material source.	39
40	Variation on aggregate gradation in stockpiles, mixing,...etc.	39
41	Monitoring mixing operations.	39
42	Compacting pattern used to achieve the desired pavement density.	39
43	Delay in contractor progress payment.	44.5
44	Limitation on material source selection, equipment type,...etc,	44.5
45	The use of dense graded job mix formula for mixture production.	44.5
46	The use of open graded job mix formula for mixture production.	44.5
47	Mix design method used locally.	49
48	Wide job mix formula tolerances.	49
49	Contractor's QC for material at mixing plant stockpiles.	49
50	Continuous changing in mix design.	49
51	Fairness of the method adopted by the MOC for deduction calculations.	49
52	Selection of the lowest bidder to construct the project.	52.5
53	Evaluation practices used for product acceptance.	52.5
54	Assignment of QC responsibility to the consultant.	55
55	Insufficient owner involvment during design phase.	55
56	Over-specification of materials and equipment,...etc.	55
57	Owner's evaluation of the contractor's material source.	57.5
58	Amount of payment deduction for non-compliance product.	57.5
59	Amount of work sub-contracted.	59

Table 10- Factor Ranking for Grade 2 Contractors.

	FACTOR	RANK
1	Pavement not designed to the regional conditions.	3
2	Climate and its relation to materials used.	3
3	Consistency of specification interpretation of aggregate quality & gradation.	3
4	Aggregate quality (e.g. gradation, shape, type,...etc.).	3
5	Amount of filler materials in the mixture.	3
6	Clarity of responsibilites and authority.	8.5
7	Mix design does not consider the local conditions.	8.5
8	Asphalt mixture properties (e.g. stability, durabilty,...ect.).	8.5
9	Availability of the specified material quality (e.g. aggregate asphalt).	8.5
10	Asphalt grade and quality.	8.5
11	The use of marginal material.	8.5
12	Design errors from inaccurate assumptions, data...etc.	16
13	Accuracy of investigation on soil type.	16
14	Accuracy of data related to traffic volume,...etc.	16
15	Consistency of specification interpretation of asphalt quality & content.	16
16	Consistency of specification interpretation of mixture composition.	16
17	Mix design method used locally.	16
18	Uniformity of material at source (ie. Aggregate gradation - asphalt grade).	16
19	Condition of road bed soil.	16
20	Qualifiction of the people performing acceptance procedures.	16
21	Qualification of the owner's inspection team.	25
22	Owners team familiarity with the construction process.	25
23	Assignment of QC responsibility to the consultant.	25
24	The use of full depth asphalt concrete cross-section.	25
25	Consistency of specification interpretation of compaction level.	25
26	QC procedure performed by the owner team during construction.	25
27	Contractor's QC for material at mixing plant stockpiles.	25
28	Owner's evaluation of the contractor's material source.	25
29	Lack of experienced staff on contractor and owner team.	25
30	Contractor's previous experience.	35
31	The use of dense graded job mix formula for mixture production.	35
32	The use of open graded job mix formula for mixture production.	35
33	Wide job mix formula tolerances.	35

Table 10- Factor Ranking for Grade 2 Contractors.

	FACTOR	RANK
34	Aggregate crushing process at material source.	35
35	Variation on asphalt content during mixture production.	35
36	Monitoring mixing operations.	35
37	Uniformity of mixture placement and compaction operations.	35
38	Roller driver experience to observe mixture behavior under roller.	35
39	Compacting at wrong time.	35
40	Over-compaction.	35
41	Contractor's financial status during construction.	44
42	Financial incentives to produce higher quality level.	44
43	Limitation on material source selection, equipment type,...etc,	44
44	Variation on aggregate gradation in stockpiles, mixing,...etc.	44
45	Continuous changing in mix design.	44
46	Paver and roller mechanical condition and type.	44
47	Compacting pattern used to achieve the desired pavement density.	44
48	Qualification of contractors during bidding process.	50.5
49	Contractor's labor and equipment capability.	50.5
50	Delay in contractor progress payment.	50.5
51	Evaluation practices used for product acceptance.	50.5
52	Amount of payment deduction for non-compliance product.	50.5
53	Fairness of the method adopted by the MOC for deduction calculations.	50.5
54	Level of technical details required to specify the desired product quality.	54.5
55	Over-specification of materials and equipment,...etc.	54.5
56	Cost escalation of material, labor ...etc.	56
57	Selection of the lowest bidder to construct the project.	57.5
58	Insufficient owner involvment during design phase.	57.5
59	Amount of work sub-contracted.	59

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Table 11 - Factor Ranking for Grade 3 Contractors.

	FACTOR	RANK
1	Amount of filler materials in the mixture.	1
2	Consistency of specification interpretation of aggregate quality.	2
3	Clarity of responsibilites and authority.	4.5
4	Mix design method used locally.	4.5
5	Aggregate quality (e.g. gradation, shape, type,...etc.).	4.5
6	Condition of road bed soil.	4.5
7	Pavement not designed to the regional conditions.	10
8	Consistency of specification interpretation of asphalt quality.	10
9	Consistency of specification interpretation of mix composition.	10
10	QC procedure performed by the contractor during construction.	10
11	Availability of the specified material quality.	10
12	The use of marginal material.	10
13	Compacting at wrong time.	10
14	Contractor's labor and equipment capability.	18
15	Design errors from inaccurate assumptions, data...etc.	18
16	Accuracy of investigation on soil type.	18
17	Climate and its relation to materials used.	18
18	Mix design does not consider the local conditions.	18
19	The use of open graded job mix formula for mixture production.	18
20	Uniformity of material at source.	18
21	Monitoring mixing operations.	18
22	Uniformity of mixture placement and compaction operations.	18
23	Qualification of the owner's inspection team.	24.5
24	Contractor's previous experience.	24.5
25	Consistency of specification interpretation of compaction level.	24.5
26	Lack of experienced staff on contractor and owner team.	24.5
27	Owners team familiarity with the construction process.	29.5
28	Wide job mix formula tolerances.	29.5
29	Asphalt mixture properties (e.g. stability, durabilty,...ect.).	29.5
30	Asphalt grade and quality.	29.5
31	Continuous changing in mix design.	29.5
32	Qualifiction of the people performing acceptance procedures.	29.5
33	Qualification of contractors during bidding process.	36
34	Selection of the lowest bidder to construct the project.	36

Table 11 - Factor Ranking for Grade 3 Contractors.

	FACTOR	RANK
35	Owner's evaluation of the contractor's material source.	36
36	Aggregate crushing process at material source.	36
37	Paver and roller mechanical condition and type.	36
38	Compacting pattern used to achieve the desired density.	36
39	Over-compaction.	36
40	Accuracy of data related to traffic volume,...etc.	42
41	The use of dense graded job mix formula for mixture production.	42
42	Contractor's QC for material at mixing plant stockpiles.	42
43	Variation on asphalt content during mixture production.	42
44	Roller driver experience to observe mixture behavior.	42
45	Contractor's financial status during construction.	46.5
46	Cost escalation of material, labor ...etc.	46.5
47	Delay in contractor progress payment.	46.5
48	Variation on aggregate gradation in stockpiles, mixing,...etc.	46.5
49	Level of technical details required to specify the desired quality.	49
50	Evaluation practices used for product acceptance.	50
51	Insufficient owner involvment during design phase.	51.5
52	Limitation on material source selection, equipment type,...etc,	51.5
53	The use of full depth asphalt concrete cross-section.	53
54	Assignment of QC responsibility to the consultant.	54
55	Financial incentives to produce higher quality level.	55
56	Fairness of the method adopted by the MOC for deduction.	56
57	Over-specification of materials and equipment,...etc.	57.5
58	Amount of payment deduction for non-compliance product.	57.5
59	Amount of work sub-contracted.	59

Table 12 - Factor Ranking for Grade 4 Contractors.

	Factor	RANK
1	Aggregate quality (e.g. gradation, shape, type,...etc.).	1.5
2	Lack of experienced staff on contractor and owner team.	1.5
3	Owners team familiarity with the construction process.	8.5
4	Contractor's previous experience.	8.5
5	Contractor's labor and equipment capability.	8.5
6	Delay in contractor progress payment.	8.5
7	Pavement not designed to the regional conditions.	8.5
8	Design errors from inaccurate assumptions, data...etc.	8.5
9	Insufficient owner involvment during design phase.	8.5
10	Accuracy of investigation on soil type.	8.5
11	Mix design does not consider the local conditions.	8.5
12	Asphalt mixture properties (e.g. stability, durabilty,...ect.).	8.5
13	Availability of the specified material quality.	8.5
14	Compacting at wrong time.	8.5
15	Clarity of responsibilites and authority.	22
16	Qualification of the owner's inspection team.	22
17	Consistency of specification interpretation of aggregate quality.	22
18	Consistency of specification interpretation of mix composition.	22
19	Consistency of specification interpretation of compaction level.	22
20	Level of technical details required to specify the desired quality.	22
21	The use of dense graded job mix formula for mixture production.	22
22	Uniformity of material at source.	22
23	Variation on aggregate gradation in stockpiles, mixing,...etc.	22
24	Amount of filler materials in the mixture.	22
25	The use of marginal material.	22
26	Monitoring mixing operations.	22
27	Condition of road bed soil.	22
28	Uniformity of mixture placement and compaction operations.	22
29	Qualifiction of the people performing acceptance procedures.	22
30	Assignment of QC responsibility to the consultant.	36
31	Qualification of contractors during bidding process.	36
32	Contractor's financial status during construction.	36
33	Cost escalation of material, labor ...etc.	36
34	Accuracy of data related to traffic volume,...etc.	36

Table 12 - Factor Ranking for Grade 4 Contractors.

	Factor	RANK
35	The use of full depth asphalt concrete cross-section.	36
36	Consistency of specification interpretation of asphalt quality.	36
37	The use of open graded job mix formula for mixture production.	36
38	QC procedure performed by the owner team during construction.	36
39	Aggregate crushing process at material source.	36
40	Asphalt grade and quality.	36
41	Paver and roller mechanical condition and type.	36
42	Roller driver experience to observe mixture behavior.	36
43	Selection of the lowest bidder to construct the project.	45.5
44	Climate and its relation to materials used.	45.5
45	Over-specification of materials and equipment,...etc.	45.5
46	Contractor's QC for material at mixing plant stockpiles.	45.5
47	Compacting pattern used to achieve the desired density.	45.5
48	Over-compaction.	45.5
49	Mix design method used locally.	50
50	Wide job mix formula tolerances.	50
51	Variation on asphalt content during mixture production.	50
52	Owner's evaluation of the contractor's material source.	53
53	Evaluation practices used for product acceptance.	53
54	Amount of payment deduction for non-compliance product.	53
55	Financial incentives to produce higher quality level.	55
56	Amount of work sub-contracted.	57
57	Limitation on material source selection, equipment type,...etc,	57
58	Fairness of the method adopted by the MOC for deduction.	57
59	Continuous changing in mix design.	59

Table 13 - Factor Ranks for all Contractor Grades.

	FACTOR	Grade 1 RANK	Grade 2 RANK	Grade 3 RANK	Grade 4 RANK
1	Clarity of responsibilites and authority.	39	8.5	4.5	22
2	Qualification of the owner's inspection team.	11	25	24.5	22
3	Owners team familiarity with the construction process.	22.5	25	29.5	8.5
4	Assignment of QC responsibility to the consultant.	55	25	54	36
5	Qualification of contractors during bidding process.	39	50.5	36	36
6	Selection of the lowest bidder to construct the project.	52.5	57.5	36	45.5
7	Contractor's previous experience.	22.5	35	24.5	8.5
8	Contractor's financial status during construction.	28.5	44	46.5	36
9	Contractor's labor and equipment capability.	16.5	50.5	18	8.5
10	Amount of work sub-contracted.	59	59	59	57
11	Cost escalation of material, labor ...etc.	33	56	46.5	36
12	Financial incentives to produce higher quality level.	22.5	44	55	55
13	Delay in contractor progress payment.	44.5	50.5	46.5	8.5
14	Pavement not designed to the regional conditions.	1	3	10	8.5
15	Design errors from inaccurate assumptions, data...etc.	4.5	16	18	8.5
16	Insufficient owner involvment during design phase.	55	57.5	51.5	8.5
17	Accuracy of investigation on soil type.	33	16	18	8.5
18	Accuracy of data related to traffic volume,...etc.	11	16	42	36
19	Climate and its relation to materials used.	11	3	18	45.5
20	The use of full depth asphalt concrete cross-section.	33	25	53	36
21	Consistency of specification interpretation of aggregate quality.	4.5	3	2	22
22	Consistency of specification interpretation of asphalt quality.	28.5	16	10	36
23	Consistency of specification interpretation of mix composition.	16.5	16	10	22
24	Consistency of specification interpretation of compaction level.	4.5	25	24.5	22
25	Level of technical details required to specify the desired quality.	39	54.5	49	22
26	Over-specification of materials and equipment,...etc.	55	54.5	57.5	45.5
27	Limitation on material source selection, equipment type,...etc,	44.5	44	51.5	57
28	Mix design does not consider the local conditions.	11	8.5	18	8.5
29	Mix design method used locally.	49	16	4.5	50
30	The use of dense graded job mix formula for mixture production.	44.5	35	42	22

Table 13 - Factor Ranks for all Contractor Grades.

	FACTOR	Grade 1 RANK	Grade 2 RANK	Grade 3 RANK	Grade 4 RANK
31	The use of open graded job mix formula for mixture production.	44.5	35	18	36
32	Wide job mix formula tolerances.	49	35	29.5	50
33	Asphalt mixture properties (e.g. stability, durabilty,...ect.).	16.5	8.5	29.5	8.5
34	QC procedure performed by the owner team during construction.	11	25	10	36
35	Contractor's QC for material at mixing plant stockpiles.	49	25	42	45.5
36	Owner's evaluation of the contractor's material source.	57.5	25	36	53
37	Availability of the specified material quality.	4.5	8.5	10	8.5
38	Uniformity of material at source.	22.5	16	18	22
39	Aggregate crushing process at material source.	39	35	36	36
40	Aggregate quality (e.g. gradation, shape, type,...etc.).	11	3	4.5	1.5
41	Asphalt grade and quality.	28.5	8.5	29.5	36
42	Variation on aggregate gradation in stockpiles, mixing,...etc.	39	44	46.5	22
43	Variation on asphalt content during mixture production.	11	35	42	50
44	Amount of filler materials in the mixture.	22.5	3	1	22
45	Continuous changing in mix design.	49	44	29.5	59
46	The use of marginal material.	22.5	8.5	10	22
47	Monitoring mixing operations.	39	35	18	22
48	Lack of experienced staff on contractor and owner team.	4.5	25	24.5	1.5
49	Condition of road bed soil.	22.5	16	4.5	22
50	Uniformity of mixture placement and compaction operations.	28.5	35	18	22
51	Paver and roller mechanical condition and type.	16.5	44	36	36
52	Compacting pattern used to achieve the desired density.	39	44	36	45.5
53	Roller driver experience to observe mixture behavior.	22.5	35	42	36
54	Compacting at wrong time.	4.5	35	10	8.5
55	Over-compaction.	33	35	36	45.5
56	Evaluation practices used for product acceptance.	52.5	50.5	50	53
57	Qualifiction of the people performing acceptance procedures.	33	16	29.5	22
58	Amount of payment deduction for non-compliance product.	57.5	50.5	57.5	53
59	Fairness of the method adopted by the MOC for deduction.	49	50.5	56	57

Appendix- D
A- SPEARMAN RANK CORRELATION

$$r_{ij} = 1 - \frac{6 * \Sigma\, di^2}{N(N^2 - 1)}$$

from table 14

$$r_{12} = 1 - \frac{6 * 14015.00}{59(59^2 - 1)} = 0.590$$

from table 15

$$r_{13} = 1 - \frac{6 * 14202.5}{59(59^2 - 1)} = 0.585$$

from table 16

$$r_{14} = 1 - \frac{6 * 14313.5}{59(59^2 - 1)} = 0.582$$

from table 17

$$r_{23} = 1 - \frac{6 * 9061.00}{59(59^2 - 1)} = 0.735$$

from table 18

$$r_{24} = 1 - \frac{6 * 19787.00}{59(59^2 - 1)} = 0..422$$

from table 19

$$r_{34} = 1 - \frac{6 * 16509.5}{59(59^2 - 1)} = 0.518$$

Where:

r_{12} = The correlation coefficient (agreement) between Grade 1 & Grade 2 contractors on the factors' Importance Index rank.

r_{13} = The correlation coefficient (agreement) between Grade 1 & Grade 3 contractors on the factors' Importance Index rank.

r_{14} = The correlation coefficient (agreement) between Grade 1 & Grade 4 contractors on the factors' Importance Index rank.

r_{23} = The correlation coefficient (agreement) between Grade 2 & Grade 3 contractors on the factors' Importance Index rank.

r_{24} = The correlation coefficient (agreement) between Grade 2 & Grade 4 contractors on the factors' Importance Index rank.

r_{34} = The correlation coefficient (agreement) between Grade 3 & Grade 4 contractors on the factors' Importance Index rank.

Table 14 - Computation Spearman Rank Correlation for Grade 1 and 2 Contractors.

	Factor	Grade 1 Rank	Grade 2 Rank	D 1 - 2	D^2
1	Clarity of responsibilites and authority.	39	8.5	30.5	930.25
2	Qualification of the owner's inspection team.	11	25	-14	196
3	Owners team familiarity with the construction process.	22.5	25	-2.5	6.25
4	Assignment of QC responsibility to the consultant.	55	25	30	900
5	Qualification of contractors during bidding process.	39	50.5	-11.5	132.25
6	Selection of the lowest bidder to construct the project.	52.5	57.5	-5	25
7	Contractor's previous experience.	22.5	35	-12.5	156.25
8	Contractor's financial status during construction.	28.5	44	-15.5	240.25
9	Contractor's labor and equipment capability.	16.5	50.5	-34	1156
10	Amount of work sub-contracted.	59	59	0	0
11	Cost escalation of material, labor ...etc.	33	56	-23	529
12	Financial incentives to produce higher quality level.	22.5	44	-21.5	462.25
13	Delay in contractor progress payment.	44.5	50.5	-6	36
14	Pavement not designed to the regional conditions.	1	3	-2	4
15	Design errors from inaccurate assumptions, data...etc.	4.5	16	-11.5	132.25
16	Insufficient owner involvment during design phase.	55	57.5	-2.5	6.25
17	Accuracy of investigation on soil type.	33	16	17	289
18	Accuracy of data related to traffic volume,...etc.	11	16	-5	25
19	Climate and its relation to materials used.	11	3	8	64
20	The use of full depth asphalt concrete cross-section.	33	25	8	64
21	Consistency of specification interpretation of aggregate quality.	4.5	3	1.5	2.25
22	Consistency of specification interpretation of asphalt quality.	28.5	16	12.5	156.25
23	Consistency of specification interpretation of mix composition.	16.5	16	0.5	0.25
24	Consistency of specification interpretation of compaction level.	4.5	25	-20.5	420.25
25	Level of technical details required to specify the desired quality.	39	54.5	-15.5	240.25
26	Over-specification of materials and equipment,...etc.	55	54.5	0.5	0.25
27	Limitation on material source selection, equipment type,...etc,	44.5	44	0.5	0.25
28	Mix design does not consider the local conditions.	11	8.5	2.5	6.25
29	Mix design method used locally.	49	16	33	1089
30	The use of dense graded job mix formula for mixture production.	44.5	35	9.5	90.25
31	The use of open graded job mix formula for mixture production.	44.5	35	9.5	90.25

Table 14 - Computation Spearman Rank Correlation for Grade 1 and 2 Contractors.

	Factor	Grade 1 Rank	Grade 2 Rank	D 1 - 2	D^2
32	Wide job mix formula tolerances.	49	35	14	196
33	Asphalt mixture properties (e.g. stability, durabilty,...ect.).	16.5	8.5	8	64
34	QC procedure performed by the owner team during construction.	11	25	-14	196
35	Contractor's QC for material at mixing plant stockpiles.	49	25	24	576
36	Owner's evaluation of the contractor's material source.	57.5	25	32.5	1056.25
37	Availability of the specified material quality.	4.5	8.5	-4	16
38	Uniformity of material at source.	22.5	16	6.5	42.25
39	Aggregate crushing process at material source.	39	35	4	16
40	Aggregate quality (e.g. gradation, shape, type,...etc.).	11	3	8	64
41	Asphalt grade and quality.	28.5	8.5	20	400
42	Variation on aggregate gradation in stockpiles, mixing,...etc.	39	44	-5	25
43	Variation on asphalt content during mixture production.	11	35	-24	576
44	Amount of filler materials in the mixture.	22.5	3	19.5	380.25
45	Continuous changing in mix design.	49	44	5	25
46	The use of marginal material.	22.5	8.5	14	196
47	Monitoring mixing operations.	39	35	4	16
48	Lack of experienced staff on contractor and owner team.	4.5	25	-20.5	420.25
49	Condition of road bed soil.	22.5	16	6.5	42.25
50	Uniformity of mixture placement and compaction operations.	28.5	35	-6.5	42.25
51	Paver and roller mechanical condition and type.	16.5	44	-27.5	756.25
52	Compacting pattern used to achieve the desired density.	39	44	-5	25
53	Roller driver experience to observe mixture behavior.	22.5	35	-12.5	156.25
54	Compacting at wrong time.	4.5	35	-30.5	930.25
55	Over-compaction.	33	35	-2	4
56	Evaluation practices used for product acceptance.	52.5	50.5	2	4
57	Qualifiction of the people performing acceptance procedures.	33	16	17	289
58	Amount of payment deduction for non-compliance product.	57.5	50.5	7	49
59	Fairness of the method adopted by the MOC for deduction.	49	50.5	-1.5	2.25
				SUM =	14015

Table 15 - Computation of Spearman Rank Correlation for Grade 1 and 3 Contractors.

	Factor	Grade 1 Rank	Grade 3 Rank	D 1-3	D^2
1	Clarity of responsibilites and authority.	39	4.5	34.5	1190.25
2	Qualification of the owner's inspection team.	11	24.5	-13.5	182.25
3	Owners team familiarity with the construction process.	22.5	29.5	-7	49
4	Assignment of QC responsibility to the consultant.	55	54	1	1
5	Qualification of contractors during bidding process.	39	36	3	9
6	Selection of the lowest bidder to construct the project.	52.5	36	16.5	272.25
7	Contractor's previous experience.	22.5	24.5	-2	4
8	Contractor's financial status during construction.	28.5	46.5	-18	324
9	Contractor's labor and equipment capability.	16.5	18	-1.5	2.25
10	Amount of work sub-contracted.	59	59	0	0
11	Cost escalation of material, labor ...etc.	33	46.5	-13.5	182.25
12	Financial incentives to produce higher quality level.	22.5	55	-32.5	1056.25
13	Delay in contractor progress payment.	44.5	46.5	-2	4
14	Pavement not designed to the regional conditions.	1	10	-9	81
15	Design errors from inaccurate assumptions, data...etc.	4.5	18	-13.5	182.25
16	Insufficient owner involvment during design phase.	55	51.5	3.5	12.25
17	Accuracy of investigation on soil type.	33	18	15	225
18	Accuracy of data related to traffic volume,...etc.	11	42	-31	961
19	Climate and its relation to materials used.	11	18	-7	49
20	The use of full depth asphalt concrete cross-section.	33	53	-20	400
21	Consistency of specification interpretation of aggregate quality.	4.5	2	2.5	6.25
22	Consistency of specification interpretation of asphalt quality.	28.5	10	18.5	342.25
23	Consistency of specification interpretation of mix composition.	16.5	10	6.5	42.25
24	Consistency of specification interpretation of compaction level.	4.5	24.5	-20	400
25	Level of technical details required to specify the desired quality.	39	49	-10	100
26	Over-specification of materials and equipment,...etc.	55	57.5	-2.5	6.25
27	Limitation on material source selection, equipment type,...etc,	44.5	51.5	-7	49
28	Mix design does not consider the local conditions.	11	18	-7	49
29	Mix design method used locally.	49	4.5	44.5	1980.25
30	The use of dense graded job mix formula for mixture production.	44.5	42	2.5	6.25
31	The use of open graded job mix formula for mixture production.	44.5	18	26.5	702.25

Table 15 - Computation of Spearman Rank Correlation for Grade 1 and 3 Contractors.

	Factor	Grade 1 Rank	Grade 3 Rank	D 1-3	D^2
32	Wide job mix formula tolerances.	49	29.5	19.5	380.25
33	Asphalt mixture properties (e.g. stability, durabilty,...ect.).	16.5	29.5	-13	169
34	QC procedure performed by the owner team during construction.	11	10	1	1
35	Contractor's QC for material at mixing plant stockpiles.	49	42	7	49
36	Owner's evaluation of the contractor's material source.	57.5	36	21.5	462.25
37	Availability of the specified material quality.	4.5	10	-5.5	30.25
38	Uniformity of material at source.	22.5	18	4.5	20.25
39	Aggregate crushing process at material source.	39	36	3	9
40	Aggregate quality (e.g. gradation, shape, type,...etc.).	11	4.5	6.5	42.25
41	Asphalt grade and quality.	28.5	29.5	-1	1
42	Variation on aggregate gradation in stockpiles, mixing,...etc.	39	46.5	-7.5	56.25
43	Variation on asphalt content during mixture production.	11	42	-31	961
44	Amount of filler materials in the mixture.	22.5	1	21.5	462.25
45	Continuous changing in mix design.	49	29.5	19.5	380.25
46	The use of marginal material.	22.5	10	12.5	156.25
47	Monitoring mixing operations.	39	18	21	441
48	Lack of experienced staff on contractor and owner team.	4.5	24.5	-20	400
49	Condition of road bed soil.	22.5	4.5	18	324
50	Uniformity of mixture placement and compaction operations.	28.5	18	10.5	110.25
51	Paver and roller mechanical condition and type.	16.5	36	-19.5	380.25
52	Compacting pattern used to achieve the desired density.	39	36	3	9
53	Roller driver experience to observe mixture behavior.	22.5	42	-19.5	380.25
54	Compacting at wrong time.	4.5	10	-5.5	30.25
55	Over-compaction.	33	36	-3	9
56	Evaluation practices used for product acceptance.	52.5	50	2.5	6.25
57	Qualifiction of the people performing acceptance procedures.	33	29.5	3.5	12.25
58	Amount of payment deduction for non-compliance product.	57.5	57.5	0	0
59	Fairness of the method adopted by the MOC for deduction.	49	56	-7	49
				SUM =	14202.5

Table 16 - Computation of Spearman Rank Correlation for Grade 1 and 4 Contractors.

	Factor	Grade 1 Rank	Grade 4 Rank	D 1 - 4	D^2
1	Clarity of responsibilites and authority.	39	22	17	289
2	Qualification of the owner's inspection team.	11	22	-11	121
3	Owners team familiarity with the construction process.	22.5	8.5	14	196
4	Assignment of QC responsibility to the consultant.	55	36	19	361
5	Qualification of contractors during bidding process.	39	36	3	9
6	Selection of the lowest bidder to construct the project.	52.5	45.5	7	49
7	Contractor's previous experience.	22.5	8.5	14	196
8	Contractor's financial status during construction.	28.5	36	-7.5	56.25
9	Contractor's labor and equipment capability.	16.5	8.5	8	64
10	Amount of work sub-contracted.	59	57	2	4
11	Cost escalation of material, labor ...etc.	33	36	-3	9
12	Financial incentives to produce higher quality level.	22.5	55	-32.5	1056.25
13	Delay in contractor progress payment.	44.5	8.5	36	1296
14	Pavement not designed to the regional conditions.	1	8.5	-7.5	56.25
15	Design errors from inaccurate assumptions, data...etc.	4.5	8.5	-4	16
16	Insufficient owner involvment during design phase.	55	8.5	46.5	2162.25
17	Accuracy of investigation on soil type.	33	8.5	24.5	600.25
18	Accuracy of data related to traffic volume,...etc.	11	36	-25	625
19	Climate and its relation to materials used.	11	45.5	-34.5	1190.25
20	The use of full depth asphalt concrete cross-section.	33	36	-3	9
21	Consistency of specification interpretation of aggregate quality.	4.5	22	-17.5	306.25
22	Consistency of specification interpretation of asphalt quality.	28.5	36	-7.5	56.25
23	Consistency of specification interpretation of mix composition.	16.5	22	-5.5	30.25
24	Consistency of specification interpretation of compaction level.	4.5	22	-17.5	306.25
25	Level of technical details required to specify the desired quality.	39	22	17	289
26	Over-specification of materials and equipment,...etc.	55	45.5	9.5	90.25
27	Limitation on material source selection, equipment type,...etc,	44.5	57	-12.5	156.25
28	Mix design does not consider the local conditions.	11	8.5	2.5	6.25
29	Mix design method used locally.	49	50	-1	1
30	The use of dense graded job mix formula for mixture production.	44.5	22	22.5	506.25
31	The use of open graded job mix formula for mixture production.	44.5	36	8.5	72.25

Table 16 - Computation of Spearman Rank Correlation for Grade 1 and 4 Contractors.

	Factor	Grade 1 Rank	Grade 4 Rank	D 1 - 4	D^2
32	Wide job mix formula tolerances.	49	50	-1	1
33	Asphalt mixture properties (e.g. stability, durabilty,...ect.).	16.5	8.5	8	64
34	QC procedure performed by the owner team during construction.	11	36	-25	625
35	Contractor's QC for material at mixing plant stockpiles.	49	45.5	3.5	12.25
36	Owner's evaluation of the contractor's material source.	57.5	53	4.5	20.25
37	Availability of the specified material quality.	4.5	8.5	-4	16
38	Uniformity of material at source.	22.5	22	0.5	0.25
39	Aggregate crushing process at material source.	39	36	3	9
40	Aggregate quality (e.g. gradation, shape, type,...etc.).	11	1.5	9.5	90.25
41	Asphalt grade and quality.	28.5	36	-7.5	56.25
42	Variation on aggregate gradation in stockpiles, mixing,...etc.	39	22	17	289
43	Variation on asphalt content during mixture production.	11	50	-39	1521
44	Amount of filler materials in the mixture.	22.5	22	0.5	0.25
45	Continuous changing in mix design.	49	59	-10	100
46	The use of marginal material.	22.5	22	0.5	0.25
47	Monitoring mixing operations.	39	22	17	289
48	Lack of experienced staff on contractor and owner team.	4.5	1.5	3	9
49	Condition of road bed soil.	22.5	22	0.5	0.25
50	Uniformity of mixture placement and compaction operations.	28.5	22	6.5	42.25
51	Paver and roller mechanical condition and type.	16.5	36	-19.5	380.25
52	Compacting pattern used to achieve the desired density.	39	45.5	-6.5	42.25
53	Roller driver experience to observe mixture behavior.	22.5	36	-13.5	182.25
54	Compacting at wrong time.	4.5	8.5	-4	16
55	Over-compaction.	33	45.5	-12.5	156.25
56	Evaluation practices used for product acceptance.	52.5	53	-0.5	0.25
57	Qualifiction of the people performing acceptance procedures.	33	22	11	121
58	Amount of payment deduction for non-compliance product.	57.5	53	4.5	20.25
59	Fairness of the method adopted by the MOC for deduction.	49	57	-8	64
				SUM =	14313.5

Table 17 - Computation of Spearman Rank Correlation for Grade 2 and 3 Contractors.

	Factor	Grade 2 Rank	Grade 3 Rank	D 2 - 3	D^2
1	Clarity of responsibilites and authority.	8.5	4.5	4	16
2	Qualification of the owner's inspection team.	25	24.5	0.5	0.25
3	Owners team familiarity with the construction process.	25	29.5	-4.5	20.25
4	Assignment of QC responsibility to the consultant.	25	54	-29	841
5	Qualification of contractors during bidding process.	50.5	36	14.5	210.25
6	Selection of the lowest bidder to construct the project.	57.5	36	21.5	462.25
7	Contractor's previous experience.	35	24.5	10.5	110.25
8	Contractor's financial status during construction.	44	46.5	-2.5	6.25
9	Contractor's labor and equipment capability.	50.5	18	32.5	1056.25
10	Amount of work sub-contracted.	59	59	0	0
11	Cost escalation of material, labor ...etc.	56	46.5	9.5	90.25
12	Financial incentives to produce higher quality level.	44	55	-11	121
13	Delay in contractor progress payment.	50.5	46.5	4	16
14	Pavement not designed to the regional conditions.	3	10	-7	49
15	Design errors from inaccurate assumptions, data...etc.	16	18	-2	4
16	Insufficient owner involvment during design phase.	57.5	51.5	6	36
17	Accuracy of investigation on soil type.	16	18	-2	4
18	Accuracy of data related to traffic volume,...etc.	16	42	-26	676
19	Climate and its relation to materials used.	3	18	-15	225
20	The use of full depth asphalt concrete cross-section.	25	53	-28	784
21	Consistency of specification interpretation of aggregate quality.	3	2	1	1
22	Consistency of specification interpretation of asphalt quality.	16	10	6	36
23	Consistency of specification interpretation of mix composition.	16	10	6	36
24	Consistency of specification interpretation of compaction level.	25	24.5	0.5	0.25
25	Level of technical details required to specify the desired quality.	54.5	49	5.5	30.25
26	Over-specification of materials and equipment,...etc.	54.5	57.5	-3	9
27	Limitation on material source selection, equipment type,...etc,	44	51.5	-7.5	56.25
28	Mix design does not consider the local conditions.	8.5	18	-9.5	90.25
29	Mix design method used locally.	16	4.5	11.5	132.25
30	The use of dense graded job mix formula for mixture production.	35	42	-7	49
31	The use of open graded job mix formula for mixture production.	35	18	17	289

Table 17 - Computation of Spearman Rank Correlation for Grade 2 and 3 Contractors.

	Factor	Grade 2 Rank	Grade 3 Rank	D 2 - 3	D^2
32	Wide job mix formula tolerances.	35	29.5	5.5	30.25
33	Asphalt mixture properties (e.g. stability, durabilty,...ect.).	8.5	29.5	-21	441
34	QC procedure performed by the owner team during construction.	25	10	15	225
35	Contractor's QC for material at mixing plant stockpiles.	25	42	-17	289
36	Owner's evaluation of the contractor's material source.	25	36	-11	121
37	Availability of the specified material quality.	8.5	10	-1.5	2.25
38	Uniformity of material at source.	16	18	-2	4
39	Aggregate crushing process at material source.	35	36	-1	1
40	Aggregate quality (e.g. gradation, shape, type,...etc.).	3	4.5	-1.5	2.25
41	Asphalt grade and quality.	8.5	29.5	-21	441
42	Variation on aggregate gradation in stockpiles, mixing,...etc.	44	46.5	-2.5	6.25
43	Variation on asphalt content during mixture production.	35	42	-7	49
44	Amount of filler materials in the mixture.	3	1	2	4
45	Continuous changing in mix design.	44	29.5	14.5	210.25
46	The use of marginal material.	8.5	10	-1.5	2.25
47	Monitoring mixing operations.	35	18	17	289
48	Lack of experienced staff on contractor and owner team.	25	24.5	0.5	0.25
49	Condition of road bed soil.	16	4.5	11.5	132.25
50	Uniformity of mixture placement and compaction operations.	35	18	17	289
51	Paver and roller mechanical condition and type.	44	36	8	64
52	Compacting pattern used to achieve the desired density.	44	36	8	64
53	Roller driver experience to observe mixture behavior.	35	42	-7	49
54	Compacting at wrong time.	35	10	25	625
55	Over-compaction.	35	36	-1	1
56	Evaluation practices used for product acceptance.	50.5	50	0.5	0.25
57	Qualifiction of the people performing acceptance procedures.	16	29.5	-13.5	182.25
58	Amount of payment deduction for non-compliance product.	50.5	57.5	-7	49
59	Fairness of the method adopted by the MOC for deduction.	50.5	56	-5.5	30.25
				SUM =	9061

Table 18 - Computation of Spearman Rank Correlation for Grade 2 and 4 Contractors.

	Factor	Grade 2 Rank	Grade 4 Rank	D 2 - 4	D^2
1	Clarity of responsibilites and authority.	8.5	22	-13.5	182.25
2	Qualification of the owner's inspection team.	25	22	3	9
3	Owners team familiarity with the construction process.	25	8.5	16.5	272.25
4	Assignment of QC responsibility to the consultant.	25	36	-11	121
5	Qualification of contractors during bidding process.	50.5	36	14.5	210.25
6	Selection of the lowest bidder to construct the project.	57.5	45.5	12	144
7	Contractor's previous experience.	35	8.5	26.5	702.25
8	Contractor's financial status during construction.	44	36	8	64
9	Contractor's labor and equipment capability.	50.5	8.5	42	1764
10	Amount of work sub-contracted.	59	57	2	4
11	Cost escalation of material, labor ...etc.	56	36	20	400
12	Financial incentives to produce higher quality level.	44	55	-11	121
13	Delay in contractor progress payment.	50.5	8.5	42	1764
14	Pavement not designed to the regional conditions.	3	8.5	-5.5	30.25
15	Design errors from inaccurate assumptions, data...etc.	16	8.5	7.5	56.25
16	Insufficient owner involvment during design phase.	57.5	8.5	49	2401
17	Accuracy of investigation on soil type.	16	8.5	7.5	56.25
18	Accuracy of data related to traffic volume,...etc.	16	36	-20	400
19	Climate and its relation to materials used.	3	45.5	-42.5	1806.25
20	The use of full depth asphalt concrete cross-section.	25	36	-11	121
21	Consistency of specification interpretation of aggregate quality.	3	22	-19	361
22	Consistency of specification interpretation of asphalt quality.	16	36	-20	400
23	Consistency of specification interpretation of mix composition.	16	22	-6	36
24	Consistency of specification interpretation of compaction level.	25	22	3	9
25	Level of technical details required to specify the desired quality.	54.5	22	32.5	1056.25
26	Over-specification of materials and equipment,...etc.	54.5	45.5	9	81
27	Limitation on material source selection, equipment type,...etc,	44	57	-13	169
28	Mix design does not consider the local conditions.	8.5	8.5	0	0
29	Mix design method used locally.	16	50	-34	1156
30	The use of dense graded job mix formula for mixture production.	35	22	13	169
31	The use of open graded job mix formula for mixture production.	35	36	-1	1

Table 18 - Computation of Spearman Rank Correlation for Grade 2 and 4 Contractors.

	Factor	Grade 2 Rank	Grade 4 Rank	D 2 - 4	D^2
32	Wide job mix formula tolerances.	35	50	-15	225
33	Asphalt mixture properties (e.g. stability, durabilty,...ect.).	8.5	8.5	0	0
34	QC procedure performed by the owner team during construction.	25	36	-11	121
35	Contractor's QC for material at mixing plant stockpiles.	25	45.5	-20.5	420.25
36	Owner's evaluation of the contractor's material source.	25	53	-28	784
37	Availability of the specified material quality.	8.5	8.5	0	0
38	Uniformity of material at source.	16	22	-6	36
39	Aggregate crushing process at material source.	35	36	-1	1
40	Aggregate quality (e.g. gradation, shape, type,...etc.).	3	1.5	1.5	2.25
41	Asphalt grade and quality.	8.5	36	-27.5	756.25
42	Variation on aggregate gradation in stockpiles, mixing,...etc.	44	22	22	484
43	Variation on asphalt content during mixture production.	35	50	-15	225
44	Amount of filler materials in the mixture.	3	22	-19	361
45	Continuous changing in mix design.	44	59	-15	225
46	The use of marginal material.	8.5	22	-13.5	182.25
47	Monitoring mixing operations.	35	22	13	169
48	Lack of experienced staff on contractor and owner team.	25	1.5	23.5	552.25
49	Condition of road bed soil.	16	22	-6	36
50	Uniformity of mixture placement and compaction operations.	35	22	13	169
51	Paver and roller mechanical condition and type.	44	36	8	64
52	Compacting pattern used to achieve the desired density.	44	45.5	-1.5	2.25
53	Roller driver experience to observe mixture behavior.	35	36	-1	1
54	Compacting at wrong time.	35	8.5	26.5	702.25
55	Over-compaction.	35	45.5	-10.5	110.25
56	Evaluation practices used for product acceptance.	50.5	53	-2.5	6.25
57	Qualifiction of the people performing acceptance procedures.	16	22	-6	36
58	Amount of payment deduction for non-compliance product.	50.5	53	-2.5	6.25
59	Fairness of the method adopted by the MOC for deduction.	50.5	57	-6.5	42.25
				SUM =	19787

Table 19 - Computation of Spearman Rank Correlation for Grade 3 and 4 Contractors.

	Factor	Grade 3 Rank	Grade 4 Rank	D 3 - 4	D^2
1	Clarity of responsibilites and authority.	4.5	22	-17.5	306.25
2	Qualification of the owner's inspection team.	24.5	22	2.5	6.25
3	Owners team familiarity with the construction process.	29.5	8.5	21	441
4	Assignment of QC responsibility to the consultant.	54	36	18	324
5	Qualification of contractors during bidding process.	36	36	0	0
6	Selection of the lowest bidder to construct the project.	36	45.5	-9.5	90.25
7	Contractor's previous experience.	24.5	8.5	16	256
8	Contractor's financial status during construction.	46.5	36	10.5	110.25
9	Contractor's labor and equipment capability.	18	8.5	9.5	90.25
10	Amount of work sub-contracted.	59	57	2	4
11	Cost escalation of material, labor ...etc.	46.5	36	10.5	110.25
12	Financial incentives to produce higher quality level.	55	55	0	0
13	Delay in contractor progress payment.	46.5	8.5	38	1444
14	Pavement not designed to the regional conditions.	10	8.5	1.5	2.25
15	Design errors from inaccurate assumptions, data...etc.	18	8.5	9.5	90.25
16	Insufficient owner involvment during design phase.	51.5	8.5	43	1849
17	Accuracy of investigation on soil type.	18	8.5	9.5	90.25
18	Accuracy of data related to traffic volume,...etc.	42	36	6	36
19	Climate and its relation to materials used.	18	45.5	-27.5	756.25
20	The use of full depth asphalt concrete cross-section.	53	36	17	289
21	Consistency of specification interpretation of aggregate quality.	2	22	-20	400
22	Consistency of specification interpretation of asphalt quality.	10	36	-26	676
23	Consistency of specification interpretation of mix composition.	10	22	-12	144
24	Consistency of specification interpretation of compaction level.	24.5	22	2.5	6.25
25	Level of technical details required to specify the desired quality.	49	22	27	729
26	Over-specification of materials and equipment,...etc.	57.5	45.5	12	144
27	Limitation on material source selection, equipment type,...etc,	51.5	57	-5.5	30.25
28	Mix design does not consider the local conditions.	18	8.5	9.5	90.25
29	Mix design method used locally.	4.5	50	-45.5	2070.25
30	The use of dense graded job mix formula for mixture production.	42	22	20	400
31	The use of open graded job mix formula for mixture production.	18	36	-18	324

Table 19 - Computation of Spearman Rank Correlation for Grade 3 and 4 Contractors.

	Factor	Grade 3 Rank	Grade 4 Rank	D 3 - 4	D^2
32	Wide job mix formula tolerances.	29.5	50	-20.5	420.25
33	Asphalt mixture properties (e.g. stability, durabilty,...ect.).	29.5	8.5	21	441
34	QC procedure performed by the owner team during construction.	10	36	-26	676
35	Contractor's QC for material at mixing plant stockpiles.	42	45.5	-3.5	12.25
36	Owner's evaluation of the contractor's material source.	36	53	-17	289
37	Availability of the specified material quality.	10	8.5	1.5	2.25
38	Uniformity of material at source.	18	22	-4	16
39	Aggregate crushing process at material source.	36	36	0	0
40	Aggregate quality (e.g. gradation, shape, type,...etc.).	4.5	1.5	3	9
41	Asphalt grade and quality.	29.5	36	-6.5	42.25
42	Variation on aggregate gradation in stockpiles, mixing,...etc.	46.5	22	24.5	600.25
43	Variation on asphalt content during mixture production.	42	50	-8	64
44	Amount of filler materials in the mixture.	1	22	-21	441
45	Continuous changing in mix design.	29.5	59	-29.5	870.25
46	The use of marginal material.	10	22	-12	144
47	Monitoring mixing operations.	18	22	-4	16
48	Lack of experienced staff on contractor and owner team.	24.5	1.5	23	529
49	Condition of road bed soil.	4.5	22	-17.5	306.25
50	Uniformity of mixture placement and compaction operations.	18	22	-4	16
51	Paver and roller mechanical condition and type.	36	36	0	0
52	Compacting pattern used to achieve the desired density.	36	45.5	-9.5	90.25
53	Roller driver experience to observe mixture behavior.	42	36	6	36
54	Compacting at wrong time.	10	8.5	1.5	2.25
55	Over-compaction.	36	45.5	-9.5	90.25
56	Evaluation practices used for product acceptance.	50	53	-3	9
57	Qualifiction of the people performing acceptance procedures.	29.5	22	7.5	56.25
58	Amount of payment deduction for non-compliance product.	57.5	53	4.5	20.25
59	Fairness of the method adopted by the MOC for deduction.	56	57	-1	1
				SUM =	**16509.5**

$F \text{ stat} = MST/MSE$

$MST = SST/(K-1)$

$MSE = SSE/(N-K)$

Where :

Fstat = The value to be compared with the critical f value

MST = Mean square for treatments

MST = Mean square for error

SST = Sume of squares of treatments

SSE = Sume of square of error

K = Number of contractor's grades = 4

N = Number of observation (cOntractors) = 31

Appendix - D

SAS Computer Output :

ANALYSIS OF VARIANCE PROEDURE :

DEPENDENT VARIABLE ; F1

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR> F	R- SQUARE	C.V
MODEL	3	2.53853047	0.84617682	1.74	0.1827	0.161923	27.3736
ERROR	27	13.13888889	0.48662551		ROOT MSE		F1 MEAN
CORRECTED TOTAL	30	15.67741935			0.697585		2.5493871

SOURCE	DF	ANOVA SS	F VALUE	PR> F
GRADE	3	2.53853047	1.47	0.1827

Appendix E

References

REFERENCES

1. Abdun-Nur, Edward "Contractual Relationship An Essential Ingredient of Quality-Assurance System." *Transportation Research Record 792*. 1981. pp. 1-3.

2. Al-Dhalaan. M. *Moc Test Road* Material and Research Department, Ministry of Communication Report, unpublished, undated.

3. Al-Jaraallah, M. and Mohan S. "Construction Management Practices in Saudi Arabia". *Transportation Research Record*, 1056, 1986, pp. 60-68.

4. Al-Musaid, A. *The Influence of Owner Involvement During Construction Process on Projects Quality* Master Thesis, KFUPM, Dhahran, 1990.

5. *Asphalt Technology and Construction Practices*. Instructors Guide. Educational Service No. (ES-1), The ASphalt Institute, Second Edition, January 1983.

6. Bayless, Robert P. "Contractor's Quality Control and Owner's Guidelines". *Journal of Professional Issues in Engineering*, Vol. 112, No. 4. October 1986. pp. 230-235.

7. Bell, C.A., Hicks, R. C., and Wilson, J. E., Effect of Percent Compaction on Asphalt Mixture Life *Placement and Compaction of Asphalt Mixture*. ASTM STP829 ed. Wagner, F.T., American Society for Testing and Materials, 1984, pp. 67-80.

8. Brown, Elton R., "Experience of Corps of Engineers in Compaction of Hot Asphalt Mixture." *Placement and Compaction of Asphalt Mixture*. ASTM STP 829 ed. Wagner, F.T., American Society for Testing and Materials, 1984, pp. 67-80.

9. Burati, James L., "Quality Control/Quality Assurance Programs." *Solution for Pavement Rehabilitation Problems*. ed. Lahue, Sanford New York: The American Society of Civil Engineers, 1986, pp. 143-158.

10. Burgess, John A., "Assuring Quality in Design Engineering." *Journal of Management in Engineering*, Vol. 4, No. 1, January 1988, pp. 16-22.

11. Clough, Richard. *Construction Contracting* John Willy and sons Inc., New York, 1981.

12. Dar-Al-handasah *Riyadh Ring Road, East Leg Report on Rutting*. Ministry of Communication Report, September 1986.

13. Dubaibe I, Khan S. and Hodok W. *A Proposal for the study of permanent Deformation in the Flexible Pavement*. Ministry of Communication Report. Un-published, undated.

14. Dukatz, E.L., and Marek, C.R., "Quality Control Aspects of Producing and Handling Aggregate for Use in Aspect Concrete Mixture." *Proceedings, Asphalt Paving Technology, 1986*.

15. Echeverry, Piego, Ibbs, W., and Burati, J. "Graduated Unit Price Payment Schedule.: *Journal of Construction Engineering and Management*. Vol. 114, No. 1, March 1988, pp. 1-18.

16. Erikson, Jim. "Meeting The Quality Management Issues on Highway Construction". *The Journal of Professional in Engineering*, Vol. 115, No. 2, April 1989, pp. 162-167.

17. Fellow K, and Regmi D. "Quality in Construction Projects: International Firms and Developing Countries". *Journal of Professional Issues in Engineering*, Vol. 116, No. 4, October 1990, pp. 388-396.

18. Geller, Myrol, "Compaction Equipment for Asphalt Mixtures". *ASTM STP-829*, ed. Wagner, F.T., American Society for Testing and Materials, 1984, pp. 28-48.

19. Gendell, David, S., and Masuda, Allen, "Highway Specification: Link to Quality." *Journal of Professional Issues in Engineering*, Vol. 114, No. 1, January 1988, pp. 17-26.

20. Halstead, Woodrow and Hughes, Charles S. "Optimizing State Contractor Relations for Improved Quality Assurance." *Transportation Research Record 792*. 1981, pp. 10-13.

21. Hay, Richard E., and Kopack, Petre A. "Relationship of Quality Control to Pavement Performance." *Solution for Pavement Rehabilitation Problems* ed. Lahue, Sanford, New York: The American Society of Civil Engineers, 1986, pp. 302-219.

22. Hughs, C.S., "State of the Art: State Acceptance of Bituminius Concrete Production and Construction Using Quality Assurance Specification." *Quality Assurance in Pavement Construction*, ASTM STP-709, American Society for Testing and Materials, 1989, pp. 11-18.

23. Hughes, C.S., "Quality Assurance Specification." *Solution for Pavement Rehabilitation Problems*. ed. Lahue, Sanford, New York: The American Society of Civil Engineers, 1986, pp. 159-164.

24. Jackson, J. "Technical Specifications Effect on Construction". *Journal of Construction Engineering and Management*, Vol. 116, No. 3, September 1990 pp. 463-467.

25. Jones, W.H., and Soherocman, J.A., "End Result Specification, A Contractors Viewpoint". *In Quality Assurance in Pavement Construction*, ASTM STP-709. American Society for Testing and Materials, 1980, pp. 28-36.

26. Kardhal, Prithul, S., and Koehler, William C., "Pennsylvania's Experience in the Compaction of Asphalt Pavements." *Placement and Compaction Asphalt Mixture* ASTM STP-829, ed. Wagner, F.T., American Society for Testing and Materials, 1984, pp. 93-107.

27.. Kasma D., "Consultant Selection *Journal of Management in Engineering*, Vol. 3, No. 4, October 1987, pp. 228-295.

28. Khan, S., Dubaihe I., and Farouki A. *Preliminary Report on Rutting* Ministry of Communication Report, September, 1986.

29. Knight, V.A., Dowdeswell, D.A., and Brien, D. "Designing Rolled Asphalt Wearing Course to Resist Deformation". *The Performance of Rolled Asphalt Road Surfacings*, Institution of Civil Engineering, London, 1979.

30. Knutson, M.J., "Building a Quality P.C. Concrete Pavement." *Solution for Pavement Rehabilitation Problems ed.* Lahue Sanford. New York: The American Society for Civil Engineers, 1986, pp. 165-185.

31. Kopac Peter A., "Current Practice in Acceptance of Bituminous Concrete Compaction." . *Transportation Research Record, 986*, 1984, pp. 165-185.

32. Lahue, S.P., "Quality Assurance and Quality of Construction." *Quality Assurance in Pavement Construction*, ASTM STP 709. American Society for Testing and Materials 1980, pp. 3-6

33. Low, Dana, E., Asin, M., and Batty, P., "Quality Control in Road Construction." *Proceeding 3rd IRF Middle East Regional Meeting*, Vol. 3, 1988, Saudi Arabia.

34. Mehaboub K, "Asphalt Concrete Creep as Related to Rutting". *Journal of Material in Civil Engineering*, Vol. 2, No.3. August, 1990, pp. 147-160.

35. Mendenhall W., *A Course in Business Statistics*. PWS publisher, Boston, 1984.

36. Meyer, A, and Hudson, W, "Guideline for material Requirements of Lo Volume Roads". *Proceedings 3rd IRF Middle East Regional Meeting*. Vol 3, 1988, Saudi Arabia pp 3.457-3.479.

123E

37. Monismith, C.L. Epps, J.A. and Finn, F.N. "Improved Asphalt Mix Design" *Proceedings, the Association of Asphalt Paving Technologists*, San Antonio, Texas, February 11-13, 1985.

38. Moore, Richard Martin, "Development of Pay Adjustment System for Asphalt Concrete Using Layered Elastic Theory. Ph.D. Dissertation, University of Washington, Seattle, 1982.

39. "Pavement Rutting in the Kingdom of Saudi Arabia" Ministry of Communication Report. Proposal, Unpublished, Undated.

40. Powel, M. Lee. "Quality Construction Can't Afford Less." *Solution for Pavement Rehabilitation Problems*. ed. Lahue Sanford. New York: The American Society of Civil Engineers, 1986, pp. 135-142.

41. *Preventive Maintenance for Saudi Arabian Road System*. Proposal Dragages Ministry of Communication Report, October, 1984.

42. *Principle of Construction of Hot-Mix Asphalt Pavement*. The Asphalt Institute Manual No. 22 (MS 22), January 1983.

43. Robbin, Robert. "Contractor's Quality Program." *Journal of Professional Issues in Engineering*, Vol. 110, NO. 3, July 1984, pp. 123-126.

44. Russell, J. "Surety Bonding and Owner-Contractor Prequalification". *Journal of Professional Issues in Engineering*, Vol. 116, No. 4, October 1990, pp. 360-374.

45. Russel, Jeffrey S., and Skibriewski Miroslaw J., "Decision Criteria in Contractor Prequalification." *Journal of Management in Engineering*, Vol. 4, No. 2, April 1988, pp. 148-164.

46. Santucci, L.E., Allen D.D, and Coats, R.L. "The Effect of Moistur and Compaction on the Quality of Asphalt Pavements.", *Proceedings. The Association of Asphalt Paving Technologists*. San Antonio, Texas., February 11-13, 1985.

47. Scheaffer. R., and Mcclave. J. *Probability and Statistics for Engineering*, Second Edition, PWS Publisher, Boston, 1986.

48. Scherocman, James, A., and Martenson, Earl, D., "Placement of Asphalt Concrete Mixtures". *In Placement and Compaction of Asphalt Mixtures*. ASTM STP-829 ed. Wagner F.T.: American Society for Testing and Materials, 1984, pp. 3-28.

49. Sandberg H., "Quality Missing Ingredient of Engineering Engagement." *Journal of Professional Issues in Engineering*, Vol. 113, No. 3, July 1987, pp. 216-220.

123E'

50. *Standard Specification for Transportation Materials and Method of Sampling and Testing, Part 1, Specification*. The American Association State Highway and Transportation Officials, AASHTO, August 1986.

51. Sterling A. *Highway Materials and Design for the Middle Eastern Environment*. Ministry of Communication Report, September, 1986.

52. Tenah R. "How is an Excellent Construction Inspection Developed". *Quality of Inspectors in Search of Excellence* ed. Welsh, Robert H., 1986 pp. 18-31.

53. Thay, Ming, Lee and Jenn-Fang Wang, "The Practice of Asphalt Concrete Quality Control in Taiwan." *Proceedings, 3rd IRF Middle East Regional Meeting*, Vol. 3, 1988, Saudi Arabia, 1988, pp. 3. 158. 3.178.

54. Walter, Jean, Hicks, R.G. Mahoney J.b. and Wilson, J.E., "Effect o Mix Vairations on Asphalt Pavement Life: North Oakland-Sourtherlin Project." *Transportation Research Record 843*, 1982, pp. 64-71.

55. Webb, A.B., "How to Build a Quality Asphalt Pavement." *Solution for Pavement Rehabilitation Problems, ed*. Lahue Sanford Press, New York: The American Society of Civil Engineers, 1986, pp. 186-202.

56. Weed, Richard, M., "Adjusted Pay Schedule, New Concept and Provision." *Transportation Research Record 986*, 1984, pp. 32-38.

57. Weingarten, Harry, Beaton, J.L., and Baker, R.F., "Specification Control of Quality." *Handbook of Highway Engineering, ed*. Baker Robert F., New York: Littan-Educational Publishing, Inc., 1975, pp. 733-768.

58. Willenbrock, Jack, H., and Kopac, Peter, A. *A Methodology for the Development of Price Adjustment System for Statistically Based Restricted Performance Specification*. Research Project No. 74-27, Research Report No. 1, The Pennsylvania Transportation Institute, October 1976.

59. Wood, Stuart, *Heavy Construction Equipment and Methods*. New Jersey: Prentice-Hall, Inc., 1977.

60. Yoder, E.J., and Witczak, M.W., *Principles of Pavement Design*, New York: John Willey and Sons, Second Edition, 1975.

61. *Highway Design and Construction* Technical Book 2, Kingdom of Saudi Arabia, Ministry of Communications, 1988.

62. *Handing over of Projects Manual*, Kingdom of Saudi Arabia, Ministry of Communications, undated.

63. *Highway Construction Manual*. Part 1, 2, and 3, Kingdom of Saudi Arabia, Ministry of Communications, undated.